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DEUTSCHE ZUSAMMENARBEIT

Irrigation manual for mango production in Southern Shan State

In cooperation with

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Irrigation manual for mango production in Southern Shan State

Produced by GIZ for the Adaptation of Agricultural Value Chains to Climate Change in Shan State project, Myanmar

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1.4 Conversion table

Besides the United States of America and Liberia, Myanmar is one of three countries, which have not adopted the International System of Units (SI). For an easier understanding, some unit conversions are listed below.

Metric			Imperial			Metric			Imperial		
1.00	Centimeter	cm	0.39	Inch	Inch	1.00	Liter	L	0.22	Gallon	Gal.
2.54	Centimeter	cm	1.00	Inch	Inch	4.55	Liter	L	1.00	Gallon	Gal.
0.30	Meter	m	12.00	Inch	Inch	1.00	Cubic meter	m^3	219.97	Gallon	Gal.
0.30	Meter	m	1.00	Foot	ft.	0.00	Degree Celcius	°C	32.00	Degree Fahrenheit	°F
1.00	Meter	m	39.37	Inch	Inch	37.78	Degree Celcius	°C	100.00	Degree Fahrenheit	°F
1.00	Meter	m	3.28	Foot	ft.	100.00	Degree Celcius	°C	212.00	Degree Fahrenheit	°F
1.00	Square meter	m^2	10.76	Square foot	sq. ft.	0.45	Kilogram	kg	1.00	Pound	lb.
4046.86	Square meter	m^2	1.00	Acre	Acre	1.00	Kilogram	kg	2.20	Pound	lb.
0.40	Hectare	ha	1.00	Acre	Acre	1.00	Metric ton	t	2204.62	Pound	lb.
1.00	Hectare	ha	2.47	Acre	Acre	1.00	Metric ton	t	0.98	Imperial ton	
0.75	Kilowatt	kW	1.00	Horsepower	HP	0.07	Bar	bar	1.00	Pound force / square inch	PSI
1.00	Kilowatt	kW	1.34	Horsepower	HP	1.00	Bar	bar	14.50	Pound force / square inch	PSI

1.5 List of abbreviations

Abbreviation	Meaning
'	Minute(s)
% v/v	Volume percent
°	Degrees
°C	Degrees Celsius
Ca	Calcium
CIm	Farmer-scheduled irrigation using micro sprinklers
CIt	Traditional irrigation
Co. Ltd.	Company Limited
d	day(s)
DAFB	Days after full bloom
E	East
e_a	Actual vapour pressure
ET	Evapotranspiration (mm)
et al.	*Et alii* (=and others)
ET_c	Potential crop evapotranspiration (mm)
$ET_{c\ adj}$	Actual crop evapotranspiration
ET_o	Potential reference evapotranspiration (mm)
e_v	Vapour pressure at saturation
F	Cumulated flow (m^3)
FAO	Food and Agricultural Organization of the United Nations
FC	Field capacity
FI	Full irrigation
ft.	Foot or feet
g	Gram(s)
G	kWh/m^2
G	Heat flux density
gal.	Gallon(s)
GIZ	Gesellschaft für Internationale Zusammenarbeit
h	Hours(s)
H	Hydraulic head (m)
HP	Horse power
Hz	Hertz
K	Potassium
k_c	Crop coefficient
k_s	Stress coefficient
kg	Kilogram(s)
km	Kilometre(s)
kPa	Kilopascal
kW	Kilowatt(s)
L	Litre(s)
L.	Linné
m	Meter(s)

Abbreviation	Meaning
mbar	Millibar(s)
MFVP	Myanmar Fruit and Vegetable Producers Association
Mg	Magnesium
mi.	Mile(s)
min	Minute(s)
MJ	Mega joule(s)
mm	Millimetre(s)
MYK	Myanmar Kyat(s)
n	Statistical number of observations
N	North
N	Nitrogen
NI	No irrigation
NRV	No return valve
O	Oxygen
OM	Organic matter
P	Power (W)
P	Phosphorus
pc	pressure compensating
PE	Polyethylene
pF	Logarithmic value for matric potential
PRD	Partial Rootzone drying
PVC	Polyvinyl chloride
PWP	Permanent wilting point
Q	Flow (m^3/s)
QTY	Quantity
Rd.	Road
RH	Relative humidity of the air (%)
R_n	Net solar radiation (MJ m^{-2} day^{-1})
rpm	Rotations per minute
R_s	Solar radiation (MJ m^{-2} day^{-1})
s	Second(s)
T	Temperature (°C)
t	Metric ton
u	Wind speed (m/s)
u_2	Wind speed in 2m height from the ground (m/s)
V	Volt(s)
W	Watt(s)
Δ	Slope of the vapour deficit curve
ϒ	Psychrometric constant (0.054 kPa/°C)

2 Introduction

This manual reflects the compiled experiences obtained over two years by the "Adaptation of Agricultural Value Chains to Climate Change in Shan State" project, implemented by Gesellschaft für Internationale Zusammenarbeit (GIZ) on behalf of the German Bundesministerium für Wirtschaftliche Zusammenarbeit (BMZ), and in cooperation with the Myanmar Ministry of Agriculture, Livestock and Irrigation (MOALI), the Shan State Department of Agriculture and the Southern Shan Mango producers' cluster of the Myanmar Fruit and Vegetable Producer Association (MFVP). The manual is built around the proven fact that water efficient irrigation allows for a more resilient mango production against weather variability and climate change, while at the same time - if managed well – ensures increased yields and better produce quality. However, GIZ understands that suitable irrigation equipment is not currently available and affordable to local farmers in Shan State. The manual therefore aims at presenting steps towards advancing easily adoptable water management techniques for the installation and operation of irrigation systems in mango production, building as much as possible upon the Southern Shan context, proposing materials and equipment readily available at local or regional markets.

2.1 What are the benefits of irrigation of mango?

Mango (*Mangifera indica* L.) is a drought resistant tree, possessing a long tap root that can go down more than 20 meters into the ground and access to ground water resources, allowing mango trees to withstand long periods of drought. Under severe drought stress, mango fruits stop vegetative growth and young leaves wilt first (Figure 1). Even when mature leaves shed, mango trees survive over several days and new buds form as soon as the rain returns.

Figure 1: When a mango tree is affected by drought, vegetative growth stops.

Mango leaves have a leathery surface and stomata are only found at the reverse, protected from direct radiation and – under stress - they close and effectively lower transpiration. This very important adaptation mechanism goes along with a reduced gas exchange and consequently, lower biomass formation. Thus, farmers can tell by experience that even though mango trees are drought tolerant, best yields can only be obtained under irrigation. After three years of comparing different levels of irrigation on Chok Anan mango trees in Northern Thailand, Spreer et. al (2009a) established a yield function based on the water supply, showing a potential of 20% higher yields under irrigation (Figure 2).

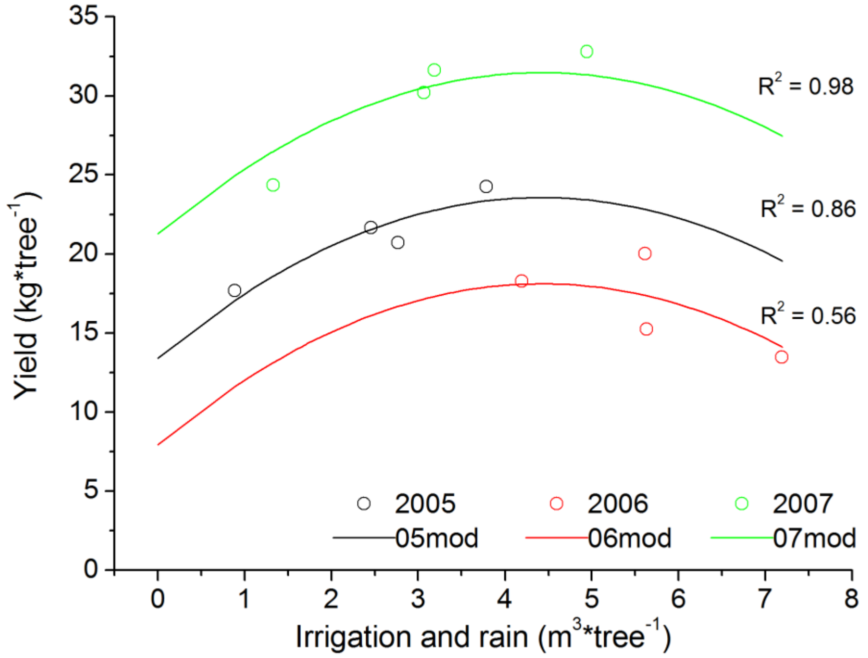


Figure 2 Mango yields of 10-year-old Chok Anan mango trees in Northern Thailand as a function of water supply. Data points represent statistical means of total fruit yield (n=80) over a period of 3 years, between 2005 and 2007, lines are yield functions based on least square analysis (Spreer et al., 2009a)

In general, irrigation positively affects yields in two ways: either by increasing the number of fruits or by enhancing individual fruit growth. The former is often attributable to an improved fruit set after flowering or reduced fruit fall during the growth period (Spreer et al., 2009a). These findings are also aligned with research efforts carried out in Mauritius (Pavel and de Villiers, 2004) and Spain (Duran Zuazo et al., 2011). Across the board, scientists unanimously state that yield differences between irrigation treatments were mainly related to the number of fruit per tree. This has distinct implications for irrigation systems in traditional and commercial mango production.

2.1.1 Traditional production

In the absence of fruit singling practiced in traditional growing systems, the number of mango fruits is highly correlated to a fruit set, which requires the absence of stress during the period after flowering (Spreer et al., 2009b; Roemer et al., 2011). Sufficient irrigation in the first period under observation ensures a higher fruit set, and is therefore, correlated to total yields of mangoes. Furthermore, this stage is of crucial importance to receive sufficient irrigation, as during that time, cell division takes place, which pre-determines size of the fruit to a certain extent. Over the course of the fruit growth there are other factors to finally determine the fate of the fruit. Figure 3 shows the results of a 2007 study analyzing fruit development under two different irrigation treatments, namely *full irrigation* (FI) and *no-irrigation* (NI), of Chok Anan mango in Northern Thailand as a function of water supply. FI treated trees were irrigated once per week at a rate of approx. 3.5 mm/d, according to data on evapotranspiration (data not shown). NI trees received rainfall only. Initially, fruit growth was faster in FI and also the fruit retention was higher. As there was no singling, the higher amount of fruit caused the yield to grow faster under FI. In the period of rapid fruit growth (40 Days After Full Bloom, DAFB), irrigated mangoes grew faster and fruit weight at 70 DAFB was about 20% higher than without irrigation. At the beginning of April (60 DAFB), heavy storms caused severe fruit drop in all treatments and, consequently, stagnation of yield formation. Following this, rainfall began and promoted fruit growth in the NI treatment to the extent that there was no difference in mean fruit weight between the treatments. This was partly due to the low number of fruit remaining on the tree in the NI treatment. However, due to the high number of fruit, the yield in FI was 32.8 kg/tree compared to 24.3 kg/tree in NI, a difference of nearly 25%.

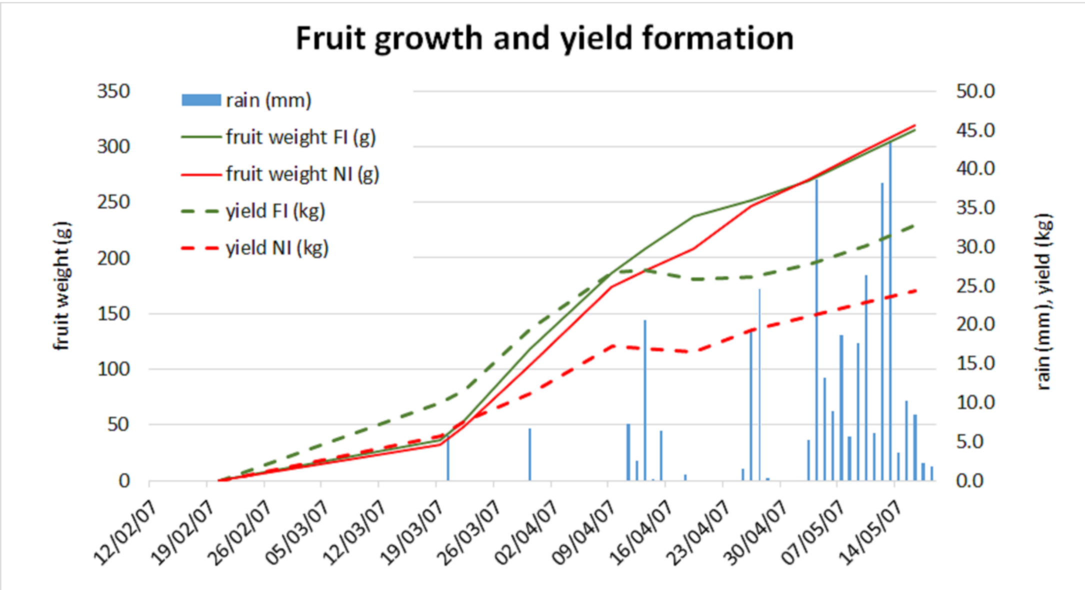


Figure 3 Fruit growth and yield formation of Chok Anan mango under full irrigation (FI) and no irrigation (NI). Fruit weight data represent mean values (n=20), yield data was estimated based on fruit weight and counted fruit load per tree (n=5). Rain data from Mae Jo weather station, Chiang Mai, Thailand.

2.1.2 Commercial system

In a commercial mango orchard, the fruit load per tree and consequently the yield are strongly influenced by fruit thinning. The amount of fruit per panicle is reduced between four and six weeks after the fruit set. The reason for this management practice is to reduce the competition between fruits with the aim of improved fruit growth. This also reduces the incidence of fruits bruising due to physical impact with other fruits in the same panicle. Producer prices are more than twice as high for mangos with a desirable fruit size and quality (clean skin, good color and good shape) as compared to those of inferior quality (Chomchalow and Songkhla, 2008). The factors that influence fruit growth are manifold. Apart from the genetic composition of the cultivar, the most important factors are fruit load, vegetative growth, and carbon: nitrogen ratio, which are in turn influenced by environmental variables, such as wind, water, light and temperature (Schaffer et al., 2009). Additionally, soil type and general management practices, especially irrigation, fertilizer application and fruit thinning, affect fruit growth. In order to produce high-quality mangos with optimal fruit size and ideal yields, a careful combination of the abovementioned management factors can result in an optimum gross return.

While the total yield, to a large extent, depends on the amount of fruit, the number of marketable mango fruit depends mainly on the size of the mango fruit. In contrast to the negative correlation between the number of fruit and fruit size documented (Spreer et al., 2009a), there is a clear positive influence of irrigation on fruit size development (Spreer et al., 2007). An experiment on a commercial orchard in Phrao (Chiang Mai Province, Northern Thailand) showed the benefits of irrigation in commercial production. 100 Nam Dokmai mango trees were irrigated at different rates and with different techniques. While yields did not differ significantly, Figure 4 shows that the fruit size distribution was best, when mango trees were fully irrigated with micro sprinklers, while traditional irrigation using a simple water hose had a substantially lower share of premium grade fruit (Schulze et al., 2013)

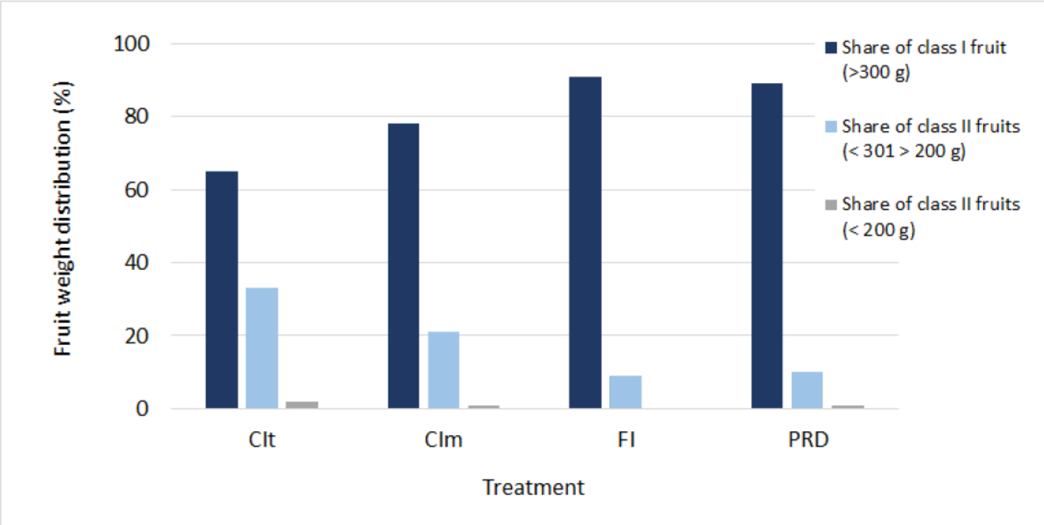


Figure 4: Fruit size distribution of Nam Dokmai mangoes in Northern Thailand under different irrigation treatments: traditional irrigation (Clt), farmer scheduled irrigation (Clm), full irrigation based on climatic water balance (FI), and deficit irrigation (Partial Rootzone Drying, PRD). (Schulze et al., 2013)

2.1.3 The impact of irrigation on mango production

Experimental data shows that, in absence of singling, a higher fruit set leads to an increase in harvested fruit under irrigation. On the other hand, if the number of fruit is reduced by singling, irrigation in the early fruit development stage has a positive effect on fruit growth, therefore drought stress should be avoided in the first two weeks after full bloom.

Most of the yield formation takes place during the stage of “rapid fruit growth” 40-80 DAFB. This is another important stage for mango production, when water and nutrients should be supplied at the optimum rate, in order to prevent reductions in yields.

Early rainfalls have the potential to contribute towards higher fruit weight in rain fed production. Thus, in years with high rainfalls the effect of irrigation may be masked by early onset of rain. On the contrary, drought stress during the late stage of fruit development has a detrimental effect on both, fruit growth and yield formation. Nagle et al. (2010) reported an early ripening of Chok Anan mangoes under non-irrigated conditions. Early ripening, produces smaller fruits and – in part – shriveled skin. For the commercial producer, early ripening is problematic as marketing contracts are normally made before harvest and fruit that is not ripe at the right time, cannot be exported. This underlines the importance of water supply in the last week before harvest. The presented data also show that mango growth does not stop, and mango fruit increase in size until being detached from the tree (Spreer et al., 2009b). Therefore, it is important to observe that irrigation or rainfall during the late stage of fruit growth can increase the number of marketable mango fruit (Fukuda et al., 2013).

3 Planning of an irrigation system for mango orchards

The following text summarizes the most important steps towards installing a micro-sprinkler irrigation system in a mango orchard. Micro-sprinklers are recommended, as they offer a higher flexibility in terms of placement with respect to the lateral line as compared to drip irrigation systems. Micro-sprinklers are also less prone to clogging and their operation easier to monitor for proper functioning.

3.1 Site selection

In principle, micro-sprinkler irrigation systems can be installed at any place, where water is available in sufficient quantity and at a pressure of more than 1 bar. However, if water has to be taken from a canal, any other surface water source or pumped from a well, energy supply must be ensured and such additional requirements taken into consideration.

3.2 Water supply

Water needs to be available in sufficient quantity for the irrigation operations. Table 1 gives an overview on the water requirement of a 1 acre mango field in the target region, assuming a 6 x 6 m (19.7 x 19.7 ft.) planting pattern and 80% of soil coverage by the canopy.

Table 1: Water requirement for 1 acre mango, 6m x 6m (19.7 x 19.7 ft.) planting, 80% soil cover. Values in m^3 are the result of a simulation with CropWat computer code (FAO, 1995). Values in gal. have been rounded to provide a better overview.

	Total irrigation requirement per season (gal. / m^3)	Weekly water requirement during peaks (gal. / m^3)
Normal rainfall		
Optimal irrigation as calculated	210,000 / 960	21,000 / 96
Deficit irrigation	150,000 / 640	15,000 / 64
50% of normal rainfall		
Optimal irrigation as calculated	250,000 / 1,130	25,000 / 113
Deficit irrigation	200,000 / 900	20,000 / 90

For irrigation lay-out and scheduling, a mobile-phone app is provided by GIZ, which is described in chapter 6.3.

Assuming a year with low rainfalls the irrigator needs to ensure a water supply of approximately 250,000 gal./acre for optimal irrigation. Years with lower than normal rainfall occur more frequently under the impression of climate change. If water is limiting, it is worthwhile to think about deficit irrigation, which can substantially reduce the irrigation water requirement (Spreer et al., 2007).

If deficit irrigation is applied, the total water requirement in a normal year amounts to approximately 150,000 gal./acre. Under these conditions, even the collection of rain water, would be a possible scenario. Assuming an evaporation from an open storage basin of 1ft./season (average 0.12 inch/day during 100 days), the seasonal evaporation loss of water storage of a basin with the surface of 3,000 ft.^{2} (e.g. 50 ft. x 60 ft.) would arise to 3,000 ft.^{3}; With a depth of 10 ft. the storage basin can store up to 30,000 ft.^{3} of water, out of which 27,000 ft^3 (168,178.56 gal.) can be used for irrigation. This is sufficient to supply the necessary irrigation water for 1 acre in one season under deficit irrigation assuming normal rainfalls. The minimum necessary collector area to supply this water during the rainy season of a normal year is 0.3 acres, assuming an off-flow of 50%. This shows that the yearly rainfall is not limiting the possibility to store water during the rainy season and use it during the dry season, but the infrastructure required for water storage is expected to become the bottle neck.

3.3 Power supply

If the irrigation water is not supplied with pressure (which is commonly the case in mango producing areas of Southern Shan), power for water pumping needs to be provided. The best-case scenario would be for the field to be close enough to the public power grid, so that the pump can be operated by electricity.

If there is no access to the public power grid, electricity can be generated at the farm by a diesel or solar generator, which implies a higher maintenance requirement. If a diesel generator is used, a variable to bear in mind is the need to supply diesel fuel during the irrigation period. A solar generator is nearly maintenance free and needs no fuel, but the upfront investment costs are generally high. The sizing of a solar generator can be estimated based on a simple arithmetic formula:

$$P = 11.6 \cdot \frac{H \cdot F}{\sum G}$$

Where P is the required nominal power in W_p, H is the hydraulic head in m, F is cumulated flow in m^3 and G the global radiation in kWh/m^2 (Hahn, 2000).

Turn-key systems of diesel or solar generators to supply pumps with electric energy are readily available in the local market. But there are also pumps, which are mechanically connected to a fuel driven engine. For these pumps, the same selection criteria apply as for electric powered pumps, as described in chapter 4.1.

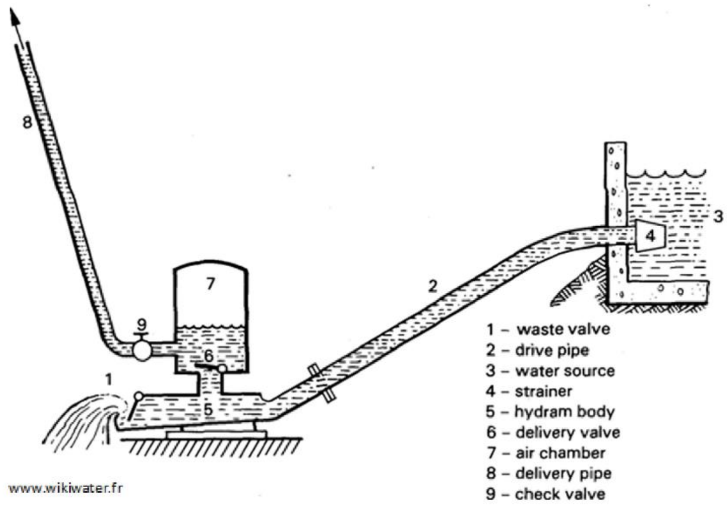


Figure 5: Functioning principle of a hydraulic ram (left); Hydraulic ram for water lifting in Hopone, Southern Shan State, Myanmar (right)

An alternative to the use of generators is that of gravity to operate an irrigation system. Drip irrigation systems can be fed by an elevated tank, which is at least 5 meters (15 ft.) above the highest tree in the orchard. In this case the gravitational force of the water itself is enough to run the irrigation system. The elevated tank itself can be situated above the field at a higher place in the topography, or on an artificial structure. The tank is necessary to guarantee a uniform pressure regime in the irrigation system, and, if surface water is used, to work as a sedimentation basin. If the tank is far away of the irrigated field, it is necessary to add approximately 10 m (30 ft.) elevation per 1 km (0.62 mi.) of distance to the orchard. Typically, elevated tanks are filled by gravity from water sources above the tank. If water is below the tank, it must be pumped. This is possible by mechanical pumps, as described above. However, there are two options, which are available in Myanmar and can be employed under specific conditions. Firstly, the hydraulic ram: As shown in Figure 5, water can be channeled over a small elevation and the kinetic energy can be used to pump a small fraction of the flow up to 10 times higher than the initial level. A comprehensive guide for installation of hydraulic rams can be found at http://www.raintree-foundation.org.

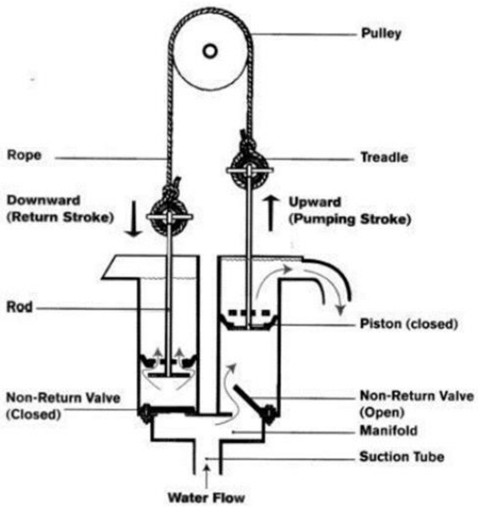


Figure 6: Functioning principle of a treadle pump for human power pumping (Kay, 2000); (right) “Baby Elephant”, a Myanmar made treadle pump (right)

Even human power can be employed for water pumping. Figure 6 shows the functioning principle of a typical treadle pump, as well as a model of a treadle pump made in Myanmar. This kind of pumps can be operated by one person without the help of external power. However, for its capacity the typical application is in small-scale gardening, rather than in commercial fruit tree production. Nevertheless, there may be specific cases where this is a suitable technology to fill a tank for a gravity fed drip irrigation system. More information can be obtained online at http://www.proximitydesigns.org/products-services/irrigation-products.

3.4 Soil and topography

The soil texture determines the optimal flow rate of the micro-sprinklers. Thus, it is beneficial to do a soil assessment before installing the irrigation system. It is not necessary to perform a full scale soil analysis. Carrying out the “finger method” as an in-field assessment will be sufficient for planning (see Chapter 8.3). If the soil is silty to clayey, an irrigation interval of one week is possible. Only on sandy soils, irrigation intervals should be 4 days or less.

If the field is on a slope, there are certain limitations with respect to the lay-out of the laterals, as they have to follow the contour lines in order to ensure a good uniformity of water distribution. If it is not possible to lay the lateral lines along the contour lines, pressure compensating (pc) sprinklers have to be used; pc-sprinklers have the same discharge rate, independent of the incoming pressure.

3.5 Orchard and management

Even though, in principle, all orchards can be irrigated by use of a micro-sprinkler irrigation system, the rather high installation cost is the reason that it is only recommendable to do the installation in well-managed, productive orchards.

The infra-structure of an irrigated orchard must be appropriate to supply the necessary inputs for optimal production, such as accessibility for maintenance operations, sufficient available labor force and the availability of fertilizers and plant protection methods. According to Liebig's law of the minimum the production is determined by the most limiting factor. Consequently, the lack of water during the dry season can be a limiting factor for production and irrigation helps to overcome that limitation. But irrigation alone cannot make an otherwise poorly managed orchard productive.

Post-harvest handling and transport facilities of the orchard further determine, whether irrigation is an economically viable way to improve production. Only if the produce can be marketed accordingly, it is possible to achieve the price premium for the additional production through irrigation. Otherwise, irrigation may help to improve yields, but missing marketing opportunities make it impossible to pay-back the investment in the irrigation system.

4 System installation and material selection

Figure 7 shows the typical parts of a micro irrigation system. At the inlet, a pump provides the required pressure for the system, unless water is supplied to the field by pipelines. The latter is not common in the mango producing areas of Southern Shan. The head station consists of the filtering system, fertilizer injection and monitoring units (flow meter, pressure gauge) – a no return valve protects the head station of water hammer. From the head station the water flows into the penstock, through a hierarchy of main and submain lines, laterals and is finally applied to the plants through emitters. This chapter will provide substantial information about the different components of a micro irrigation system.

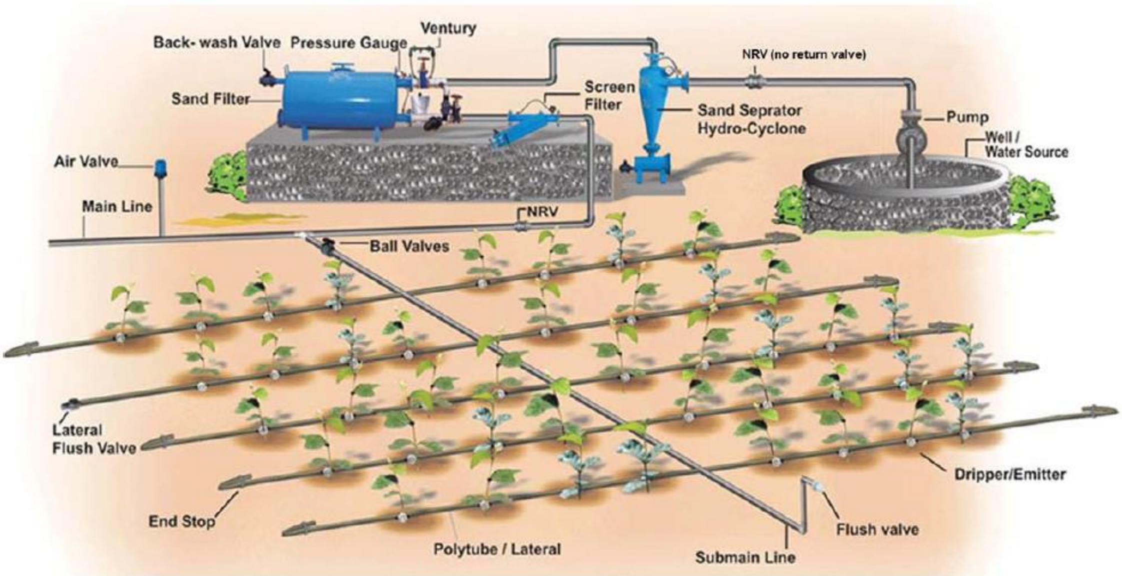


Figure 7: Components in a typical set-up of a micro-irrigation system (picture: www.jaindrip.com)

4.1 Pump

As mentioned above, when water is taken from surface water resources or a well, it has to be transported by pumping. Further, a pressure of more than 1 bar (14.5 PSI) needs to be produced to operate the micro-sprinklers. Assuming that mango trees are planted 6m x 6m (19.7 ft. x 19.7 ft.), there are roughly 100 trees on one acre. Thus, it can be assumed that a centrifugal pump powered by 2 kW (2.68 HP) engine is enough to operate the irrigation system. If water is taken from a well, a submersible pump must be used. About additional 1 kW (1.34 HP) is needed per 30 m (100 ft.) of depth. This chapter shall describe the different aspects, which need to be considered, when selecting an appropriate pump for the irrigation system. Some of the calculation procedures are simplified in order to enable practitioners to perform the pump selection themselves.

In this manual it is not possible to provide a review on actual pumps available in Myanmar. So, in terms of material selection, quality standards and warranty issues, the user needs to find out the best choice of pump. The following sub-chapters will hereby help in the process of sizing pump and motor.

In Figure 8 a typical electric motor pump is depicted and the relevant parts are identified.

As a first step, the motor must be matched with the power supply. However, most motors would be laid out for 220V and 50Hz and can be operated with one and three phases power supply. The power of the motor itself is given either in “horse powers” (HP) or in kilo Watt (kW), whereby 1 kW = 1.34 HP.

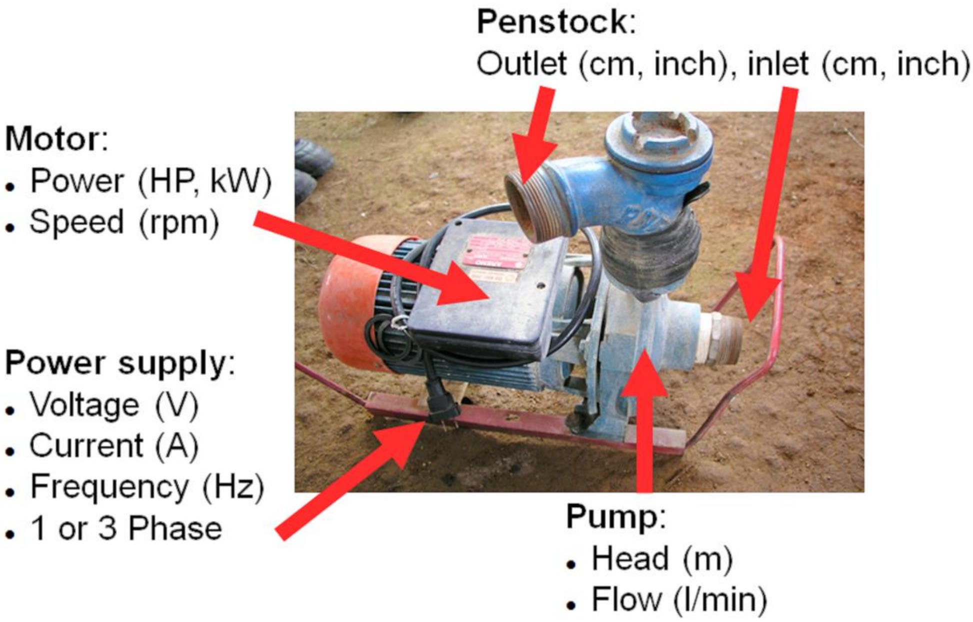


Figure 8: Parts of an electric-powered single stage centrifugal pump

Normally, there is a fixed set of a pump connected to a motor. Therefore, it is common place to describe the power of the combination by the power of its motor. Even though the power of the motor is correlated to the hydraulic power of how much water can be delivered, pumps may vary with respect to efficiency. This is important to observe, when using pumps for different tasks. Therefore, it is necessary to consider the maximum flow (Q) of the pump and the maximum head (H) of the motor-pump-combination. This information is provided by the manufacturer of the pump.

__Figure 9:__ Example for the signboard with technical data of a motor-pump-combination

Nowadays, many pump manufacturers offer sizing tools online. Using this kind of aids, it is possible, to find a pump that precisely fits the requirement for the specific application and also select an engine accordingly. However, in agricultural supply stores located in mango-producing areas of Southern Shan State, this logistical support is rarely available and the information provided to the user is limited to a simple signboard with the general specifications of the motor pump combination, similar to the signboard shown in Figure 9.

Based on the combination of H and Q it is possible to see, whether the pump is good enough for the application needed. As indicated in Figure 10, the combinations of H and Q can be plotted in a diagram to illustrate the suitability of the pump. It shows the different performance of two pumps with the same engine power. While pump A (ASUNO TD2005) has a lower maximum H, it is more appropriate to pump at higher Q. For the situation of H < 10 m, pump A has the higher pumping rate. That means that with the same energy input, more water can be pumped. This in turn means that there is a shorter duration and, consequently, lower cost for energy. In contrast, pump B (ARENO DS2008B) can deliver more water for H > 10 m.

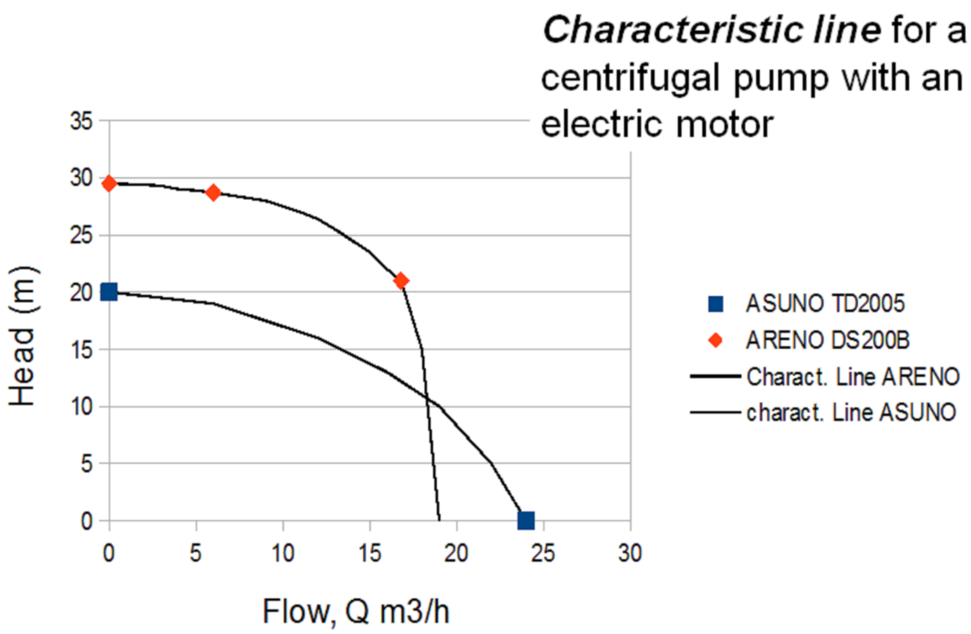


Figure 10: Combination of head (H) and flow (Q) characteristics of two pumps with the same motor power (2 HP, 1.5 kW)

4.1.1 Calculation example for pump selection

The following example shall briefly illustrate how a rough calculation can be carried out to estimate the requirements of a pump. This is an overly-simplified technical approach and, in doubt, an expert should be consulted.

Example:

- Water is taken from a well with a depth of 100 ft., thus the static Head is equivalent to 30.5 m.
- The distance between the well and the irrigation system is less than 3000 ft. As a general rule, we assume that the pressure loss in the main pipe is 1 bar/km (0.3 mbar/ft.).

- The system should service 100 micro-sprinklers with a flow rate of 70 L/h (18.5 gal./h) at the same time. The pressure requirement at the inlet of the system is 2 bars (considering filter and venture nozzle installation). The total discharge is 7.0 m^3/h (1850 gal./h).

Component	**Head (ft.)**	**Head (m)**	**Flow (m^3/h)**	**Flow (gal./h)**
Static head	100.0	30.5		
Water transport	32.8	10.0	7.0	1,850
Irrigation system	65.6	20.0		
Total	**198.7**	**60.3**	**7.0**	**1,850**

After this rough calculation the Head / Flow requirements for the pump are the combination of H = 60 m and Q = 7.0 m^3/h. As a general rule, it would be safe to assume that under good operation conditions a pump would operate at 60% of H_{max} and Q_{max} at the same time. Therefore, we calculate H_{max} as follows:

$$H_{max} = H / 0.6 = 60 \text{ m} / 0.6 = \mathbf{100 \text{ m}}$$

And Q_{max} as follows:

$$Q_{max} = Q / 0.6 = 7.0 / 0.6 = \mathbf{12 \text{ m}^3/\text{h}}$$

Thus, in order to meet the minimum requirements for this specific irrigation system, one should select a pump that has a combination of **H_{max} = 100 m** (328 ft.) and **Q_{max} = 12 m^3/h** (2,640 gal./h).

4.2 Head-station

The head-station should contain the following items:

- Flow meter
- Main valve
- No-return valve
- Air ventilation valve
- Pressure sensor or manometer
- Primary filter (e.g. disc filter)
- Secondary filter (e.g. mesh / screen filter)
- Fertiliser injection unit (e.g. venutri nozzle)

If different crops are irrigated, it is recommended to have a sub-head station at the inlet of each sub-field with a separate venturi nozzle (see chapter 4.5) and a secondary filter (Figure 11).

Figure 11: Sub-head station with fertilizer injection and secondary filter (picture: S. Chotivan)

4.3 Penstock

The orchard should be serviced by a main line consisting typically of a 2” penstock. According to a market survey in Southern Shan State, it is recommendable to use PVC pipes, which are locally available. In general, PVC pipes should be buried in the ground to protect them from UV radiation and physical damage.

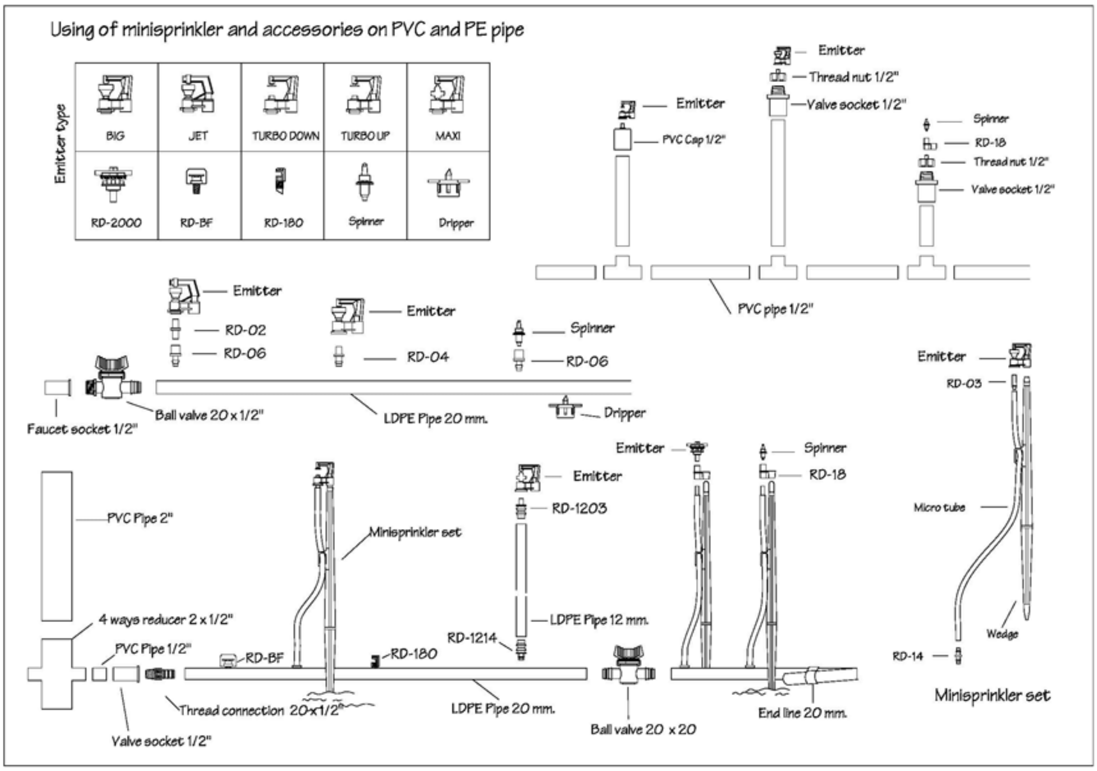


Figure 12: Mounting of different emitter types on PE and PVC laterals. Example taken from Eastern Agritek®, products of other companies are used in similar fashion.

The whole irrigated field is typically divided in subfields of about 100 – 150 trees. Each subfield is connected to the main line by a submain line with a 1.5" penstock and an inlet valve in order to irrigate different portions of a field. On the submain line the laterals are mounted. For the lateral line 20mm PE pipes are recommended. If a good quality PE-pipe is not available, micro-sprinklers can be mounted on ¼" PVC pipes with special adapters (Figure 12).

4.4 Emitters

4.4.1 Drippers and micro-sprinklers

As "emitters", which are organs to apply water to the trees, there is – generally – the choice between drippers and micro-sprinklers. Some general features of both emitter types are listed in Table 2.

Table 2: Comparison between drippers and micro sprinklers

Drippers	**Micro sprinklers**
Cheaper, even when using 6-8 drippers per tree	*Easy management*: Their function is easily monitored, and maintenance and replacement of spare parts is possible
High application efficiency. Under drip irrigation, there is virtually no water loss	*High application rate*. Shorter application time means saving labor and energy by avoiding long running times for pumps
Low pressure. Drip irrigation systems are appropriate for gravity fed systems	*Medium pressure*. Micro-sprinklers systems typically use pumps

There is a variety of drippers and micro-sprinklers. Some examples will be presented in the following section:

Drip lines

Drip lines come with built-in drippers at regular distances. Typically, dripper spacing is up to 20 inches, which is often not suitable for tree crops. Therefore, drip lines are generally used for row crops, such as potatoes or strawberries.

There are two major types, which are:

- *Drip pipes*, made from solid PE material, which can be used for several years.
- *Drip hoses* or *lay-flat drip lines*, made from thin-layer plastic, which are disposable after one irrigation season.

Plug-on drippers

Plug-on drippers should be used in combination with good quality PE pipes. With their low-pressure requirement, these kind of drippers are a recommendable solution for gravity-fed irrigation systems. Plug-on drippers can be flexibly spaced, are cheap and quick to be replaced.

Micro sprinklers

Micro sprinklers are the most sophisticated type of emitters. Water is distributed evenly by a rotating deflector, which may vary in form and shape. Some micro-sprinklers feature a pressure compensation function for sloping lands (see below). Micro sprinklers have a higher application rate and a higher pressure requirement than drippers. Therefore, they are normally used along with pumps

Micro-sprayers

Micro-sprayers are similar to micro-sprinklers, but with a static deflector. Normally they are used for more narrow spacing than micro-sprinklers with rotating deflector. Similarly, they are easy to monitor in their operation. Also maintenance is easy and single spare parts can be replaced if necessary.

4.4.2 Emitter testing

To supply all trees with water and save water at the same time, it is important that the emitters selected have a reasonable uniformity. That means that all of the emitters release the same amount of water at the same time.

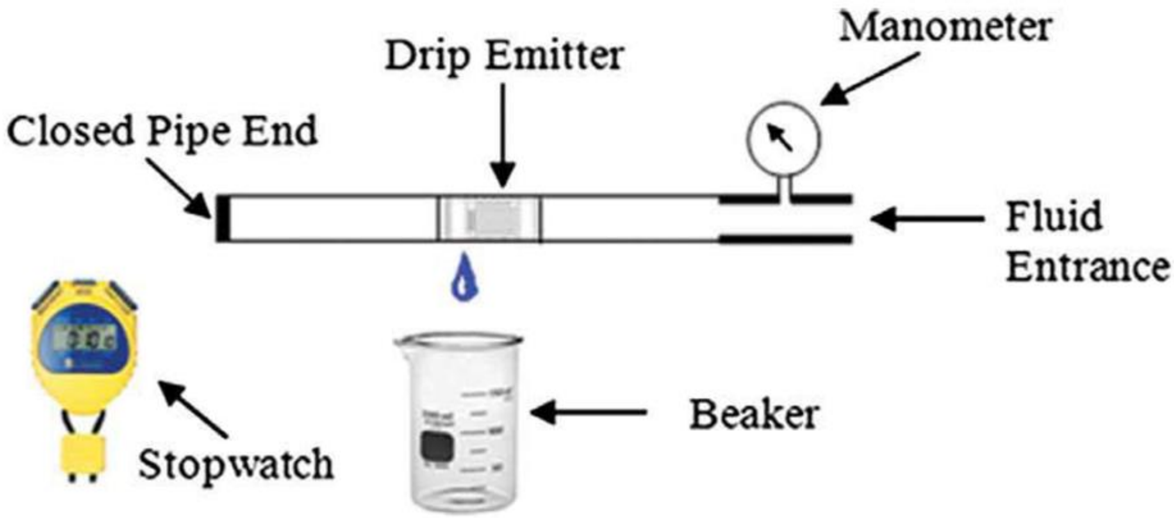


Figure 13: Set-up to test emitter uniformity (Celik et a., 2011)

If working with an unknown type of emitters it is advisable to test some units first. Therefore, some drippers or micro sprinklers are mounted onto a pipe with a closed end and variable pressure is applied to the emitters (Figure 13). With a manometer at the inlet of the pipe, it is possible to determine the minimum pressure requirement, under which the emitters exhibit desirable functions. For the sole purpose of determining uniformity, a manometer is not necessary.

Figure 14: Field testing of micro-sprinklers (left);a cut-open water bottle enables to capture all the water from a micro-sprinkler into a bucket (right)

For practical field testing, there is a ball valve positioned at the inlet of the pipe. Water pressure is provided by pump or by gravity. Three test runs are performed, with three different “positionings” of the ball-valve: (a) open, (b) ½ open, (c) ¼ open. The degree of opening the valve does not need to be exact, as the same conditions apply for all tested emitters. At least 4 emitters should be mounted on the pipe and tested (Figure 14). For each positioning, water is applied during 1 minute and collected in one beaker per emitter. The amount of water emitted from each emitter is determined and the mean value is determined. The amount of each emitter should be in the range of +/- 10% as compared to the mean value.

4.4.3 Pressure compensating emitters

Some producers offer pressure compensating emitters. There are mostly identified by "pc" in the name. They feature a plastic membrane which narrows the emitter's cross section with increasing pressure. Thus, all emitters of this type in an irrigation system will have the same application rate, independent of the pressure applied. That is useful, if the irrigation system is on a sloping field, where differences in pressure are high due to the differences in gravity.

Suppliers of high end technical irrigation systems in Myanmar:

Prime Agri Technologies (Myanmar) Limited

Suite (101), Pin Lon Hteik Htar Tower (Blazon), U Wisara Road, Kamayut Township, Yangon, Myanmar

A.T.C Supply (1993)

119 (C) Thanlwin Road, Kamayut Township, Yangon, 11041 Myanmar

Some companies in Thailand which sell micro-irrigation equipment are:

Eastern Agritek Co. Ltd.
38/1 Thesaban Street Tb.n Thanggian A. Phoklaeng, C. Rayong 21110
Thailand
E-Mail: info@raindrop-th.com, raindrop_th@hotmail.com
Web-site: www.raindrop-th.com
Tel.: 038 671 207

Netafim (Thailand) Co., Ltd
2170 Bangkok Tower, Room no. 1802, 18th Floor, New Phetchburi Road, Bangkapi, Huaykwang, Bangkok 10310, Thailand
E-mail: netafim@netafim.co.th
Website: www.netafim.co.th
Tel: +66-2308-0100, Fax: +66-2308-0105

During the survey in the mango producing areas of Southern Shan, a retailer stated that the following company sells irrigation equipment to Myanmar:

Super Products
13 Navanakorn Rd., Klongnueng, Klongluang District,
Pathumthani 12120, Thailand
Tel (02) 520 4891-9
Fax (02) 908 5617
http://www.superproducts.co.th

4.5 Fertilizer injection

There are many ways for fertilizer injection. In the example of the simple GIZ design (Chapter 5), the fertilizer is applied suction-sided. This is a cheap method, which can be applied in field irrigation where, fertigation events are not plentiful. The disadvantage of suction-sided injection is that the fertigation solution passes through the pump and has corrosive effect on it.

For pressure-sided injection, only one example will be presented in this manual: The Venturi nozzle. It is a cheap and reliable way to inject fertilizer. Typically, units are made from plastic and have a long life-span. The nozzle contracts the water flow through a small orifice and based on the contraction of flow, a suction is created where the nozzle opens again (Figure 15).

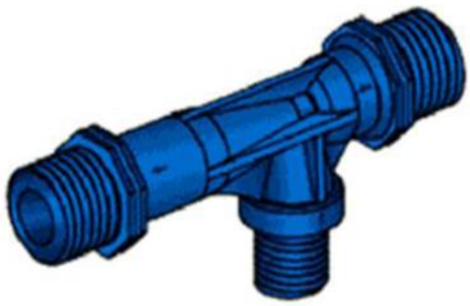


Figure 15: Venturi nozzle as used for fertilizer injection (left); Cross section of a venture nozzle (right) (pictures: http://irrigationdirect.com.au)

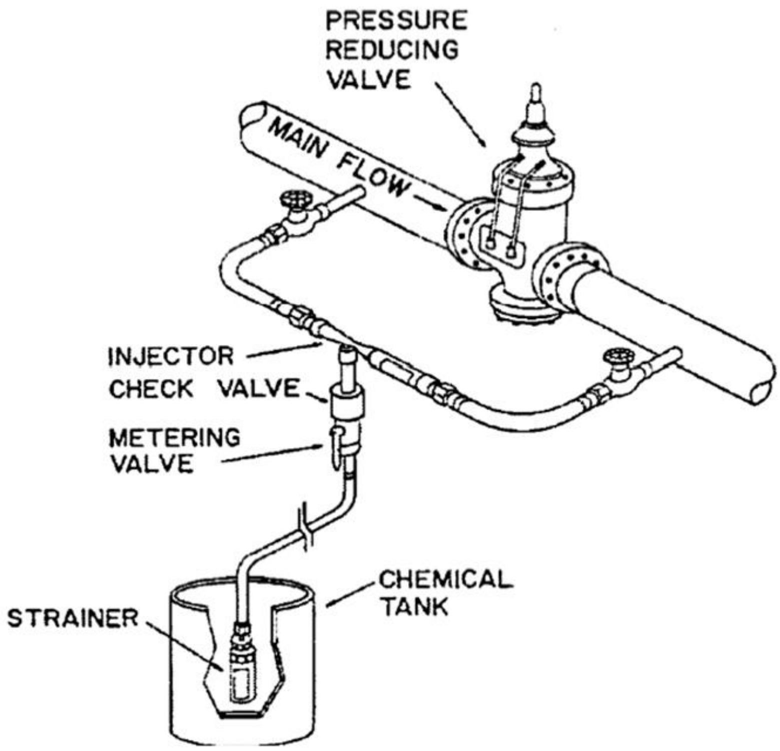


Figure 16: Installation of a Venturi nozzle on a by-pass to the main line (graphic: www.bidgeepumps.com.au)

The Venturi nozzle does not need external power, but decreases the pressure in the injection line considerably. Therefore, it is not mounted on the main line directly, but rather on a bypass as shown in **Figure *16***.

4.6 Filtering of the irrigation water

Depending on the source of the irrigation water there is an e inherent need for filtration:

- *Well water*
  - Normally unproblematic

- *Water from streams*
  - Sediments (soil erosion)
  - Chemical residues
  - Debris

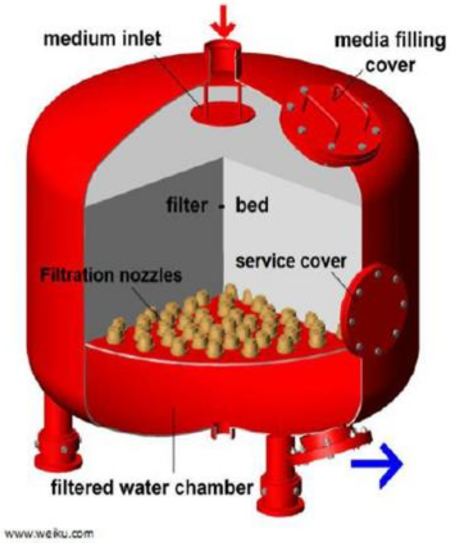
- *Reservoirs*
  - Growth of algae
  - Dust deposition
  - Debris

When fertigation is practiced, it is advisable to use two filters: (a) a primary filter for filtration of the water when entering the system and (b) a secondary filter to remove possible contaminants by the fertigation, e.g. non-dissolved fertilizer particles.

Media filter
Used as primary filter.

- For all types of pollutants
- High capacity
- Pressure loss
- Expensive
- Maintenance required

For higher capacity and automatic back-flush, media filters can be used in parallel arrangement.



Disc filter
Used as primary and secondary filter.

- Medium capacity
- Good for silt and bigger particles
- Lower effectiveness when removing organic pollutants

For higher capacity and automatic back-flush, disc filters can be used in parallel arrangement. Single operation requires frequent cleaning.

Screen filter
Used mainly as secondary filter, but it can be used as primary filter only when water for irrigation is clean from the source

- High capacity
- Only rough mechanical filtering

5 The GIZ-design for small scale irrigation projects

Nowadays, companies offer design and installation services all over Myanmar (p.26). They provide turn-key solutions with a high level of quality in terms of materials used and installation. For larger scale agricultural enterprises, it is recommendable to seek this kind of service. For smaller scale projects this may not be a cost-effective solution, as small-scale irrigation systems can perform very well in the field, using high quality materials, but with a much simpler system lay-out.

The following examples describes the lay-out of a series of GIZ model farms in Southern Shan State, which have been equipped with simplified irrigation systems.

5.1 Example 1: Micro-sprinkler irrigation system with booster pump

Orchard Location: 20° 47.178'N, 97° 13.735'E

Amount of trees to be irrigated: 144

Spacing / avg. canopy diameter: 18 x 18 ft (5.5 x 5.5 m) / 16 ft (5 m)

Theoretical max. daily irrigation requirement per tree: 17 gal. (75 L)

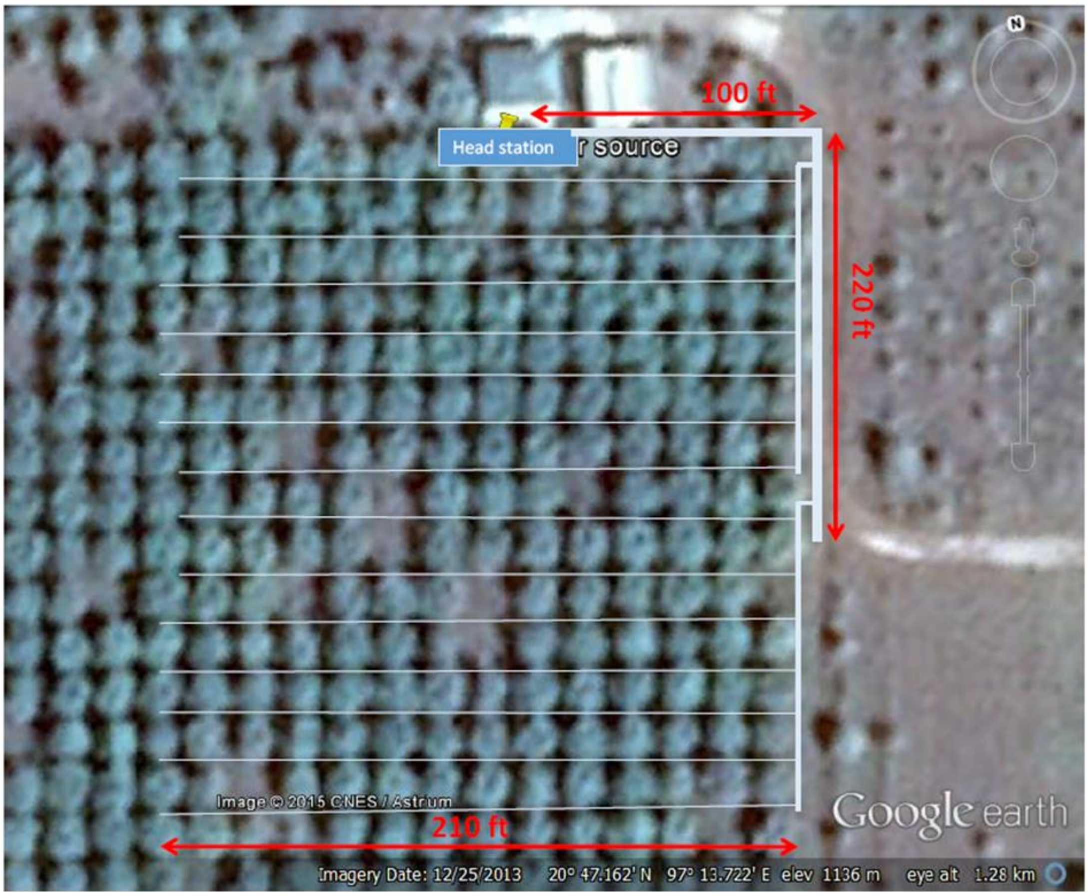


Figure 17: Sketch of the micro-sprinkler irrigation system in Hopone Southern Shan State

For irrigation, the field was split into two sub-fields, as shown in **Figure *17***. The main line of 2" was laid from the head station to the upper (north-eastern) end of the field following the road. Two submain lines of 1.5” develop the sub-fields with 7 lateral lines each and 14 irrigated trees. Each tree is equipped with two micro-sprinklers Raindrop TD70 (Figure 21).

The head station was reduced to the most essential components, as depicted in Figure 18.

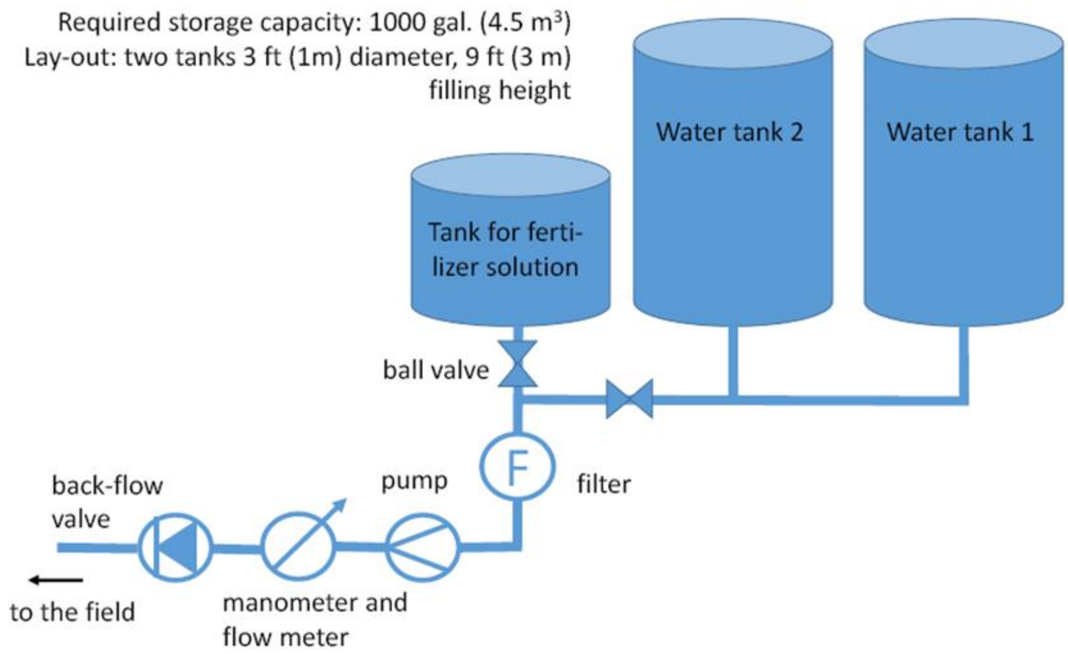


Figure 18: Sketch of the head station for irrigation system with booster pump and fertigation

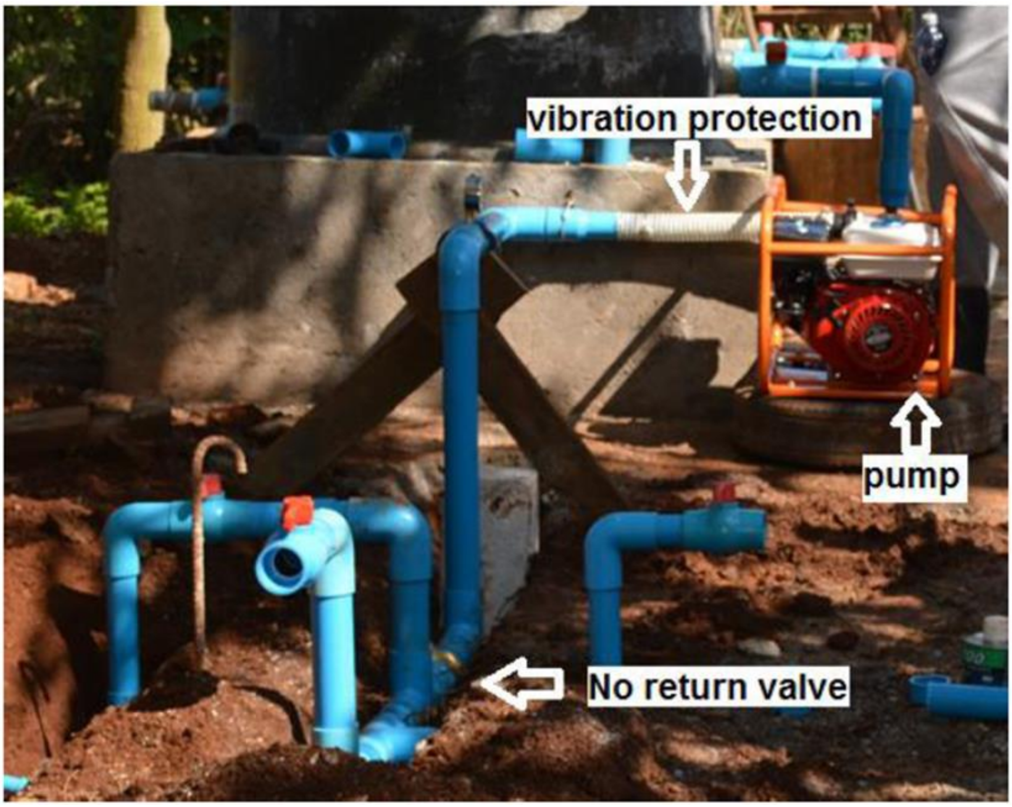


Figure 19: Head station with pump and inlet of the mainline

The head station was designed to keep installation costs low, however, good quality materials were imported from Thailand, as they were not available at the local market. **Table 3** gives an overview on the material use with a cost calculation from 2016. The tank was built by the farm owner in the frame of the project and is, therefore, not considered in this calculation.

Table 3: Material list for the installation of a micro irrigation system with booster pump

Description	Unit	QTY	Unit price (MMK)	total (MMK)
Head station:				
Pump, 4 kW, engine	pc	1	110,000	110,000
Screw fittings for pump connection	pc	2	1,600	3,200
Water meter 2", max. 20 m3/h	pc	1	0	0
Back flow valve 2"	pc	1	15,000	15,000
Disc filter 120 mesh (130 micron), 2"	pc	1	30,000	30,000
Manometer 0-4 bar (incl. T-connector for 2")	pc	1	15,000	15,000
PVC pipes and fittings:				0
Pipe 2"	19 ft	17	5,600	95,200
T-connector 2"	pc	3	500	1,500
Elbow connector 2"	pc	7	300	2,100
Straight connector 2"	pc	12	300	3,600
Ball valve 2"	pc	4	2,300	9,200
Reducer 2" - 1.5"	pc	2	500	1,000
Pipe 1.5"	19 ft	12	3,600	43,200
Elbow connector 1.5"	pc	2	300	600
Ball valve 1.5"	pc	1	1,600	1,600
Connectors 1.5" PVC to 3/4" PE	pc	14	600	8,400
PE pipe and material				0
Pipe 20 mm (3/4")	600 ft	6	30,000	180,000
Straight connector 20 mm	pc	10	100	1,000
Other materials				
Wire, 0.5 mm	kg	1	750	750
Teflon	role	5	350	1,750
Glue	500g	2	2,500	5,000
Micro-sprinklers, Raindrop TD70 (2 per tree)	pc	350	1,000	350,000
Puncher for sprinkler installation	pc	1	2,600	2,600
Total estimated cost (MMK)				880,700

The nominal pressure to operate the system is 1.5 bars, operating one sub-field at a time. Switching between sub-fields is done by manual ball valves.

The ends of the main and submain lines are closed with a ball valve. By opening the valves the penstock can be flushed with clear water. The PE laterals are just folded at the end and can also be opened for maintenance. Flushing should be done at least once at the beginning and at the end of the irrigation season, respectively. If the penstock and the micro-sprinklers remain in the field during the rainy season, a monthly rainy season irrigation helps prevent insects from getting into the pipes.

Figure 19 and Figure 20 show how the head-station was set-up in the field.

Figure 20: Head station with storage tanks

Figure 21: Orchard with Raindrop TD70 micro-sprinklers with static deflector

5.2 Example 2: Gravity-fed dripper system

Location: 21° 10.241'N, 96° 47.410'E

Water supply: stream, high tank

Capacity: 2000 gal.

Amount of trees to be irrigated: 100

Spacing / avg. canopy diameter: 20 x 25 ft (6 x 8 m) / 15 ft (5 m)

Theoretical max. daily irrigation requirement per tree: 17 gal. (75 L)

Theoretical max. daily water use: 1700 gal.

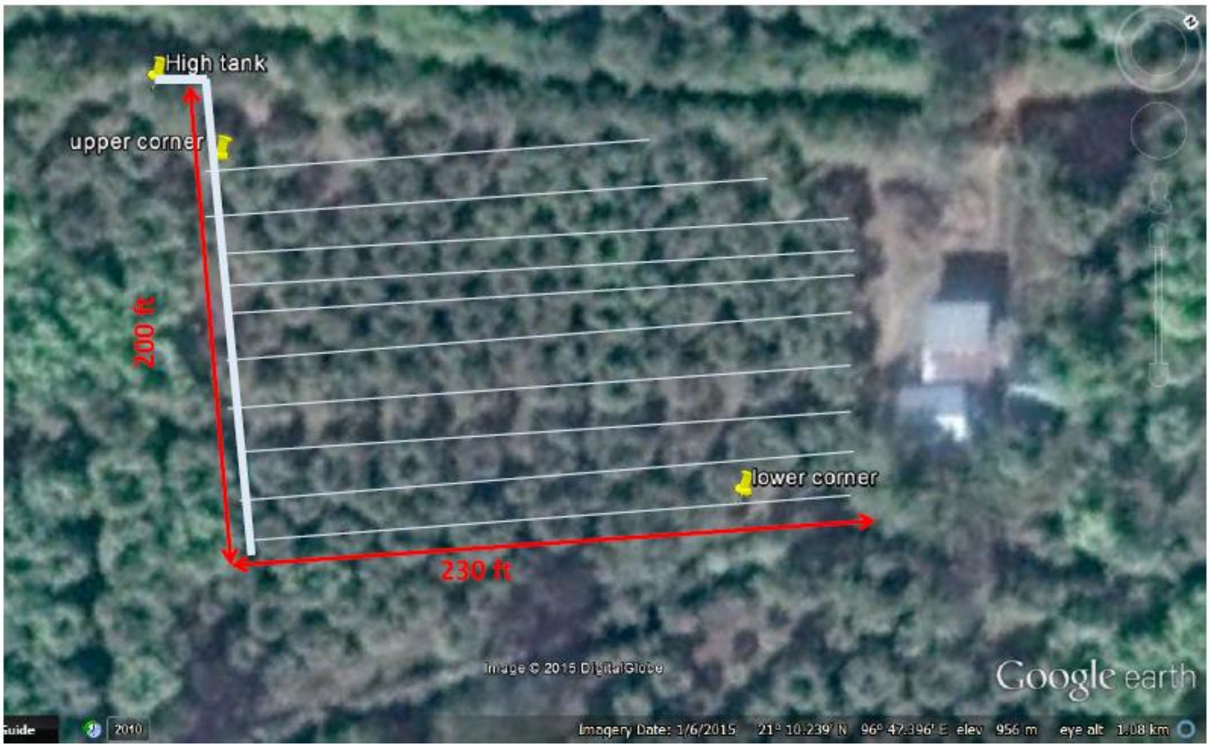


Figure 22: Sketch of the gravity-fed drip-irrigation system in Lawksawk Southern Shan State

The gravity-fed irrigation system is the simplest set-up used in the irrigation project. An elevated tank provides enough gravitational force to operate the system, if the water table is at least 5m above the uppermost tree of the field. Instead of a head station there is only a main valve and the filter (disc filter, 120 mesh / 130 micron) at the inlet to the main line (Figure 23). The mainline consists of a 2" PVC pipe, buried in the ground, following the slope. Without submain lines, the laterals are directly connected to the main line, and laid perpendicular to the slope along the contour lines. All laterals have a ball valve at the inlet, so that each line of trees can be irrigated separately (Figure 24). Each tree is equipped with four Netafim® PCJ4 drippers with a nominal flow rate of 4 L/h. For the installation, a tool specifically designed for making holes with sharp edges is used in order to guarantee an exact fit of the drippers on the pipe and avoid water losses (Figure 25).

Table 4 Material list for the installation of a gravity-fed micro irrigation system

Description	Unit	QTY	Unit price (MMK)	total (MMK)
Head station:				
Water meter 2", max. 20 m3/h	pc	1	0	0
Disc filter 120 mesh (130 micron), 2"	pc	1	30,000	30,000
Manometer 0-4 bar (incl. T-connector for 2")	pc	1	15,000	15,000
PVC pipes and fittings:				0
Pipe 2"	19 ft	12	5,600	67,200
Elbow connector 2"	pc	2	300	600
Straight connector 2"	pc	12	300	3,600
Ball valve 2"	pc	2	2,300	4,600
Connectors 1.5" PVC to 3/4" PE	pc	4	600	2,400
Nozzle	pc	4	600	2,400
Male socket	pc	4	300	1,200
PE pipe and material				0
Pipe 20 mm (3/4")	600 ft	5	30,000	150,000
Straight connector 20 mm	pc	5	100	500
Other materials				
Wire, 0.5 mm	kg	1	750	750
Teflon	role	5	350	1,750
Glue	500g	2	2,500	5,000
Micro-sprinklers, Raindrop TD70 (2 per tree)	pc	380	100	38,000
Puncher for dripper installation	pc	1	2,600	2,600
Total estimated cost (MMK)				325,600

Figure 23: Elevated tank, main valve and filter at the inlet of the main line of the gravity-fed drip-irrigation system.

Figure 24: Downhill installation of the main line and direct connection of laterals

Figure 25: Tool for making exact hole with sharp edges, necessary to install plug-on drippers.

For all micro irrigation systems, it is important to use good quality PE-pipes and make exact holes. Figure 26 shows the difference between a well-functioning dripper and a faulty installation. For the selection of PE pipes from an unknown producer, it is recommended to manually check a sample. Therefore, one should take along a PE-connector and a lighter. One end of the PE pipe is heated up and the connector inserted. After cooling down the pipe must be in tight contact with the connector, otherwise, it is not recommendable to use this pipe (Figure 27). After that, take about 5 m of pipe and pull the hand along. The pipe must have a smooth surface and the diameter must not vary.

Figure 26: Left: Well-installed plug-on dripper; no leakage – the exact amount of water is delivered to the plant. Right: Leaking dripper due to sub-optimal pipe material used.

Figure 27: Left: A good PE pipe is attached to a connector, tightly fitting the profile. Right: A low quality PE pipe is fixed to a connector by use of a wire.

6 Irrigation management

Irrigation management can follow different principles, which will be explained in short in this chapter. Generally, the irrigator of mango trees may orient on the following catch points, when planning the irrigation schedule:

- Start irrigation after full bloom
- Irrigate in one week intervals (or according to other farm procedures)
- Optimize intervals to replenish water used by plants or fill up rootzone
- Sensitive times are short after fruit set (first two weeks) and time of rapid fruit growth (40-80 days after full bloom)
- When necessary, apply deficit irrigation outside sensitive times

6.1 Start of irrigation season

Irrigation should be started at full bloom. During the winter months, it is important that irrigation is stopped. The trees need this time of drought in order to support good flower induction. If irrigation is performed throughout the dry season, the flower induction is reduced and less flowers are formed. Irrigation can start right after flower induction. However, this irrigation cannot be used by the tree for fruit growth. Economically, that is lost irrigation. In contrast irrigation after full bloom is used by the tree for yield formation and fruit retention.

6.2 Irrigation intervals

The right irrigation interval depends on the size of the trees and the kind of soil. With a light (sandy) soil, the irrigation intervals should be shorter and smaller quantities of water should be applied. On heavy, clayey soils the intervals may be longer and higher amounts of water are applied at the same time. Beyond the physiological needs, it makes sense to choose an interval that integrates well in other farming operations. Therefore, a one-week-interval is mostly suitable. The irrigation using a hose, typically at high application rates and long intervals between the irrigation events may have disadvantages: If a high amount of water is irrigated, the water content in the soil is higher than the field capacity, which means that all soil pores are filled with water and the gas exchange in the root zone is temporarily obstructed. If this is followed by a long period without irrigation, the water content in the soil may be lowered to the extent that water uptake is reduced due to high water retention under drought conditions.

6.3 Irrigation scheduling

In principle, there are three ways to schedule irrigation:

1. Based on soil water status
2. Based on plant related parameters
3. Based on *climatic water balance* calculations

These three principles are explained in the following section, including two practical examples, applicable in the mango producing areas of Southern Shan.

6.3.1 Irrigation scheduling based on soil water status

The rootzone is the space where plants acquire water and nutrients. Thus, it is a good idea to base irrigation scheduling on whether there is enough water in the soil or not. Consequently, irrigation water is applied, if the water in the soil is not enough and application is stopped, when there is enough water in the soil. Thus, the ability of scheduling irrigation based on soil water status depends on the availability of soil moisture data. Nowadays, there are several methods to determine the water content in the soil. *Time Domain Reflectometry* (TDR) or *Frequency Domain Reflectometry* (FDR) are technologies to determine the presence of water in the soil, based on the differences in di-electric properties between water and soil. Modern automatic irrigation schemes use TDR for irrigation scheduling, because it allows a precise *in-situ* determination of the amount of water in the soil in real time. For farms with a lower level of technological development, however, TDR may not be the option of choice as there is not enough supportive infrastructure to make use of the data obtained.

6.3.1.1 Tensiometers

The following section shall introduce the use of tensiometers, a cheap and precise way to monitor the degree of water supply in the rootzone (Figure 28).

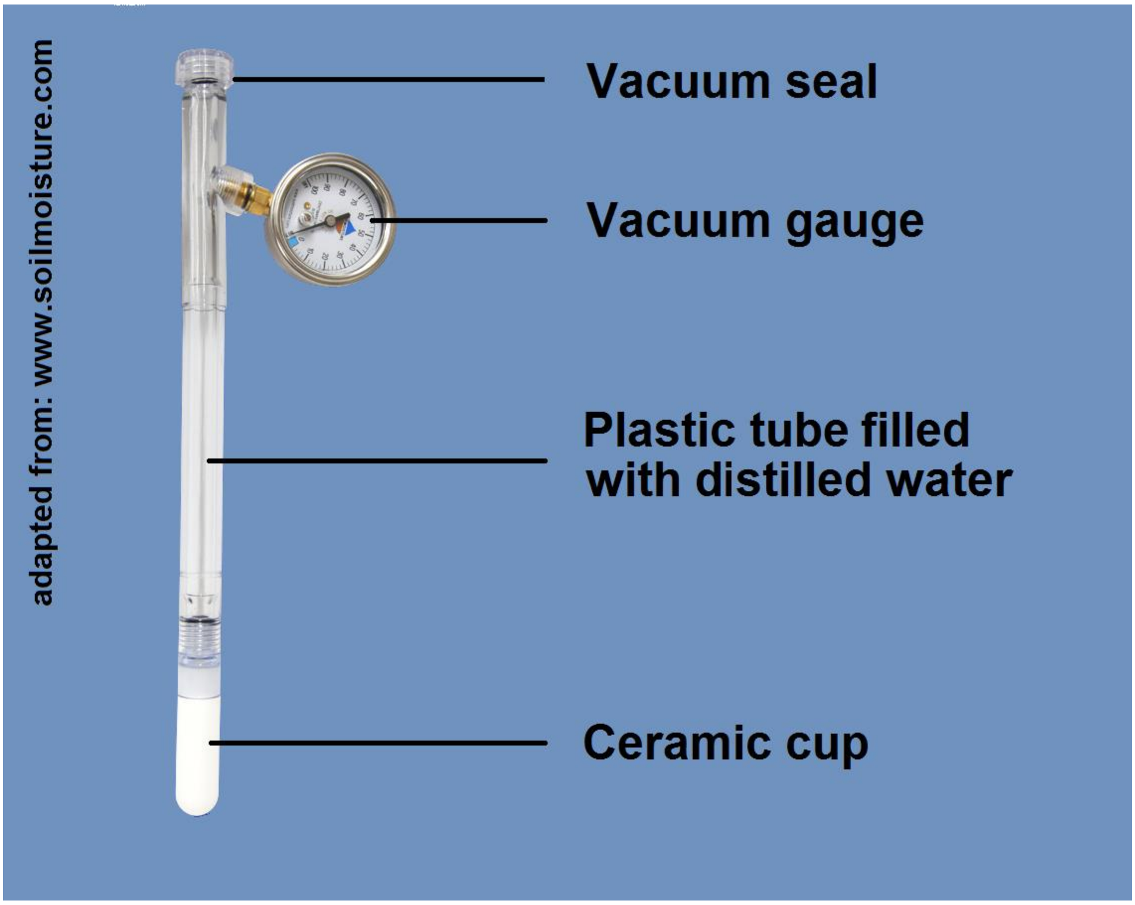
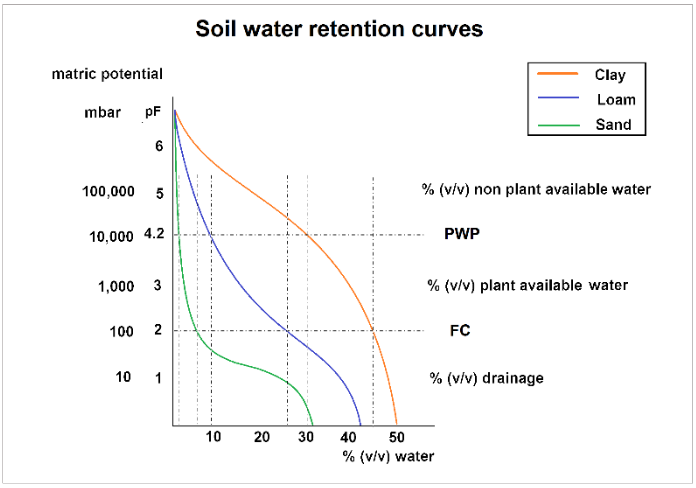


Figure 28: Functional parts of a tensiometer

A tensiometer consists of an evacuated tube which is filled with distilled water. It is sealed on one side and has a ceramic cup on the other end. This ceramic cup is introduced into the soil in a way that there is a good fit with the surrounding soil. Through this contact the ceramic is exposed to the matric potential (see box below) of the soil. Thus, shortly after installation there will be an equilibrium between the matric potential, which is the force to pull water out of the tensiometer and the vacuum inside the tensiometer, which is the counteracting force to keep water inside the device. In a drying soil, the matric potential increases and more water is pulled out of the tensiometer, increasing the vacuum in the pipe. If the soil is re-wetted (e.g. by irrigation or rain), the vacuum causes the water to enter the tensiometer. Therefore, there is always an equilibrium between the matric potential of the surrounding soil and the vacuum inside the tensiometer. The vacuum is measured by a vacuum gauge, which can be mechanic (as depicted in Figure 28) or electronic. The latter enables the connection to a data logger and continuous monitoring.

A tensiometer provides information on how well the soil is supplied with water. Therefore, it is an excellent tool for irrigation scheduling. A mechanic tensiometer typically costs between 20 and 60 US$, electronic devices may be more expensive, depending on the peripheral equipment required.

Water in the soil



The soil is a porous body, which consists of mineral and organic compounds. In the spaces between the soil particles – the "pores" – there may be air or water. Depending on the soil texture (clay, silt, sand) the pores have a different size distribution. In a clayey soil, there is a high amount of fine pores, which by capillary forces retain the water more strongly than larger pores, which are more numerous in a sandy soil. Therefore, a clayey soil can store much more water than a sandy soil. The "matric potential" determines how strong the water is bound in the soil texture. It is measured in millibar (mbar). However, as the most relevant levels of matric potentials are between 100 and 10,000 mbar, a logarithmic scale is applied, the so called "pF-value". The amount of water that the soil can hold against gravity, is called "field capacity (FC)" and is defined as pF 2.0. At this point, the soil holds enough water for plants to take up. If there is more water than FC, it will percolate below the root-zone, if drainage is possible, otherwise, there is water-logging, which negatively affects the gas exchange of plants. A pF value of 2.8 is critical to most tree crops and they start to experience water stress. At pF 4.2 the "Permanent Wilting Point (PWP)" is reached. This means that even there is water in the soil, plants cannot use it, because it is strongly bound to the fine pores in the soil body. The graph above shows water retention curves for different soil types: A sandy soil typically has less than 10% total available water. Drainage may start at less than 10% volumetric water content. A clay soil, in contrast, can store more than 40% water, but only 10 – 20% are plant available.

6.3.1.2 Irrigation scheduling by use of tensiometers

For irrigation scheduling, tensiometers are typically used in pairs. The pair of tensiometers should be installed at a representative location in terms of soil properties and topography (see chapter 3.4). On a field with different soil properties and topographic conditions, more than one pair of tensiometers should be used.

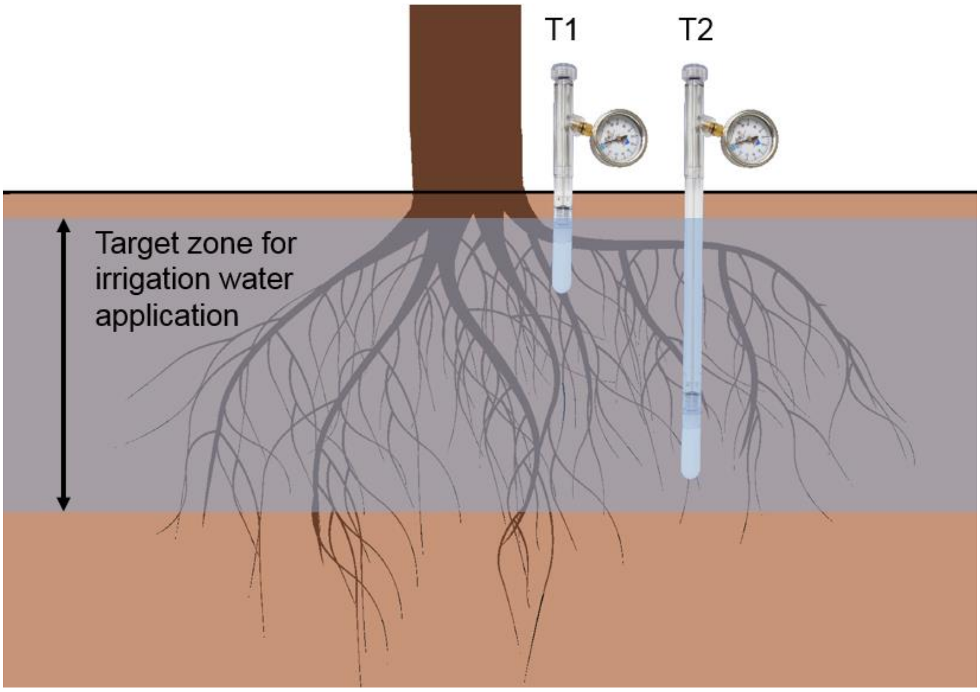


Figure 29: Placement of a tensiometer pair for irrigation scheduling

Figure 29 shows the positioning of a pair of tensiometers for irrigation scheduling. The depth varies according to crop and soil depth and, as a general rule,T1 is placed at ¼ of the depth of the rootzone and T2 at ¾ of the depth of the rootzone. For a mango tree on a deep undisturbed soil, a positioning at a depth of 20 cm (8 inch) and 60 cm (24 inch) for T1 and T2, respectively, is a good choice. Even though the root system of a mango tree is deeper, this covers a substantial part of the active roots.

The decision when to start irrigation is taken based on the reading of the upper tensiometer T1: If the value of 700 mbar (pF 2.8) has been reached, irrigation should be initiated. For the first irrigation event, 60 L/m^2 should be irrigated on a sandy soil and 120 L/m^2 on a loamy or clayey soil. 24 hours after the irrigation event, the tensiometers are checked again. If both tensiometers show 100 mbar (pF 2.0) the irrigation water applied was enough to supply water to the entire target zone of irrigation (Figure 29). For the next irrigation event the amount of water is reduced by 10%. The procedure is repeated until T2 has a value above 100 mbar (pF 2.0) 24 hours after the last irrigation). This means that the water applied was not enough for the wetting front to reach the lower part of the target zone. In this case, the amount of water applied should be increased again by 10% (Figure 30). After that, the amount of water applied can remain constant, as long as both tensiometers read 100 mbar (pF 2.0) 24 hours after stopping the irrigation.

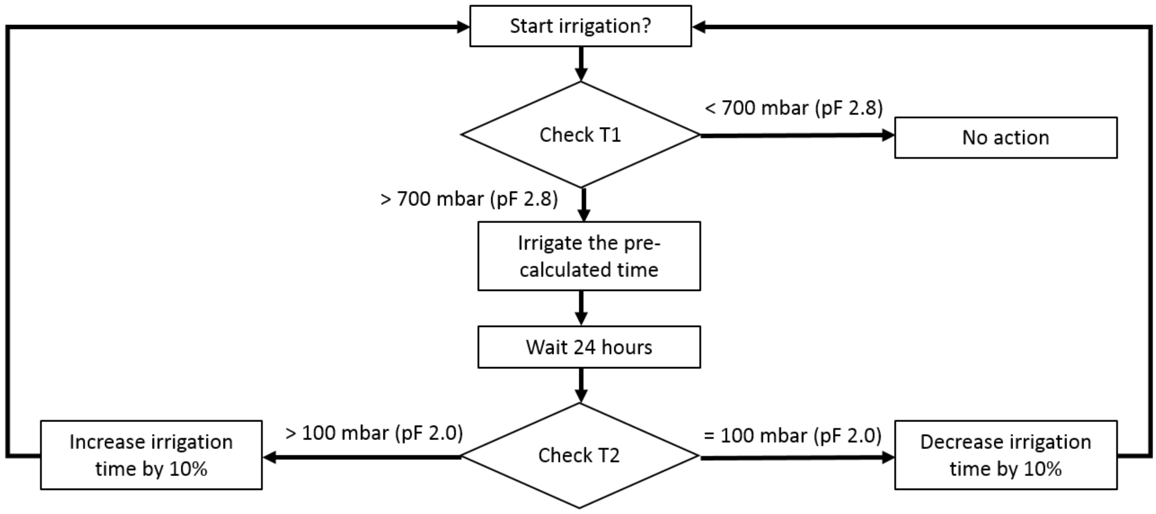


Figure 30: Flow chart to decide the amount of irrigation applied based on tensiometer readings.

6.3.1.3 Installation of a tensiometer

Before installing the tensiometer, the device must be filled completely with distilled water and left to repose for 24 hours with the ceramic cup submerged in a bucket of clean (or distilled) water. To check the tensiometer, remove it from the bucket and wrap cloth around the ceramic cup. Press gently for some minutes. After a short time the reading of the vacuum gauge should rise to approx. 100 mbar. If this is not the case, the tensiometer is not working correctly. In most cases the reason is a defective or improperly installed vacuum seal on the top of the tensiometer. Make sure that the seal is tight. If the tensiometer still doesn't react, it is defective and should be repaired by the manufacturer.

For the installation of a tensiometer it is important to guarantee good contact between the ceramic cup and the surrounding soil. Therefore first drill a hole in the soil to the desired depth to place the tensiometer. The diameter of the hole should be slightly bigger than the one of the tensiometer. Take a portion of soil material and mix it with water in order to obtain a wet sludge. Fill the hole with the wet sludge and gently press the tensiometer in to the desired depth. At the end press some extra soil material tightly around the upper part of the tensiometer in order to prevent rain or irrigation water to enter alongside the tensiometer. If the tensiometer is correctly installed, there will be a reading after a few minutes (Figure 31). At the beginning this reading is of course over estimating the soil moisture due to the fact that the surrounding soil material still has a higher moisture than the rest of the soil. After 24 hours, the soil moisture has reached an equilibrium and the tensiometer data correctly display the degree of water supply in the soil.

Tensiometers can be used to monitor moisture levels of 0 mbar (pF 0.0) (=water logging) over 100 mbar (pF 2.0) (=field capacity, FC) up to 900 mbar (pF 2.95). Beyond 900 mbar the soil is so dry that air enters through some medium pores which are in contact with the tensiometer. The air is sucked in by the vacuum, which subsequently brakes down. Without vacuum the water freely drains through the ceramic cup and the tensiometer runs dry. Short after that, the tensiometer can be refilled and resealed to continue the measurement. However, if a tensiometer has fallen dry for more than 24 hours, it should be removed and re-installed. To remove the tensiometer, gently turn it until you feel the contact with the surrounding soil is broken. If a tensiometer is just recklessly pulled out of the dry soil, the ceramic cup might break.

Figure 31: Installation of a tensiometer

6.3.2 Climatic water balance

The amount of water use of a crop depends on species and site conditions. Any environmental or management factor, which is not at optimum, causes an alternation in crop water use. Not-ideal conditions may comprise of biotic stresses (pest / disease pressure) and abiotic stresses (lack of nutrients, as well as heat-, cold- or drought stress). Assuming these factors are optimum, the variables influencing the crop water use are weather parameters. Therefore, the Food and Agricultural Organization of the United Nations (FAO) has adapted a calculation procedure developed by Howard Penman and John Monteith, which enables the determination of crop water use based on weather parameters: temperature (T), relative humidity of the air (RH), wind speed (u) and solar radiation (R_s).

The following shall summarize the calculation procedure to calculate crop water use. Figures, equations and descriptions are taken from "*Allen RG, Pereira JS, Raes D, Smith M, 1998. Crop Evapotranspiration - Guidelines for Computing Crop Water Requirement. Food and Agricultural Organisation of the United Nations, Rome, Italy*" no individual referencing was done in this section.

As depicted in *Figure 32* the water requirement for any cropped surface is determined as evapotranspiration (ET), which consists of evaporation from the open soil surface and transpiration by the plants. The potential reference ET (ET_0) is based on climate parameters only. By use of a crop coefficient (k_c) and one or more stress coefficients (k_s) it is possible to calculate the potential crop ET (ET_c) according to the crop species, the phenological stage and potential stress factors, respectively.

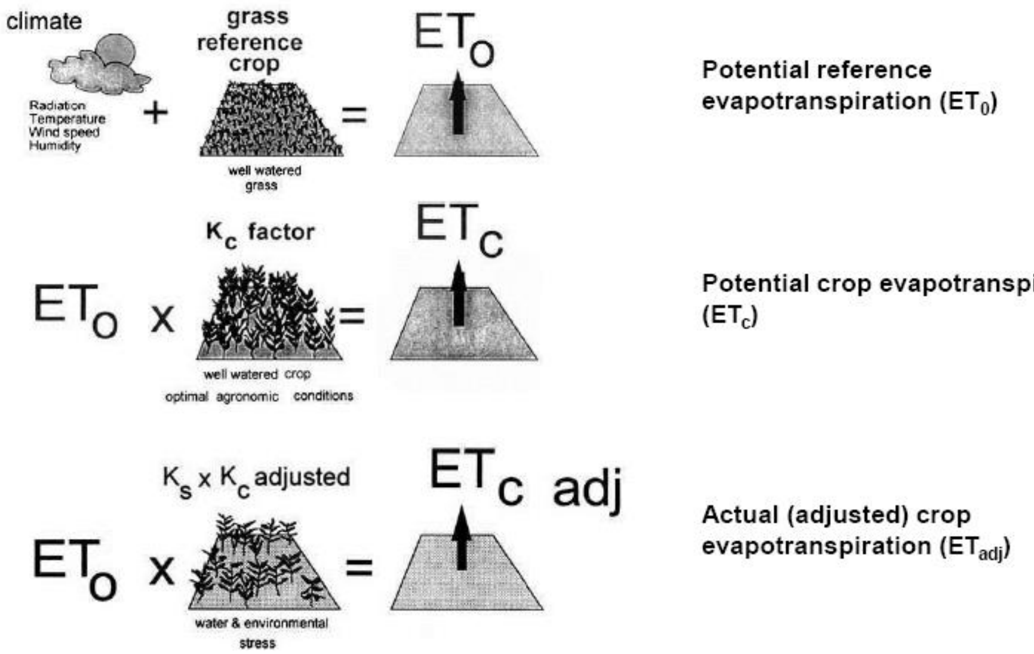


Figure 32: Procedure to determine the actual water use of a crop according to the FAO method

ET_0, as the first step in the water balance is calculated according to the modified Penman-Monteith Equation in mm/d:

$$ET_0 = \frac{0.408 \cdot \Delta \cdot (R_n - G) + \gamma \cdot \frac{900}{T + 273} \cdot u_2 \cdot (e_s - e_a)}{\Delta + \gamma \cdot (1 + 0.34 \cdot u_2)}$$

In this equation ϒ (0.054 kPa/°C) is a constant, also called psychrometric constant. The soil heat flux density (G) is 0, if no freezing or thawing occurs. Thus the required data to solve the equation are as follows:

6.3.2.1 Temperature (T)

The average daily maximum and minimum air temperatures in degrees Celsius (°C) are required. Where only average mean daily temperatures (T) are available, the calculations can still be executed but some underestimation of ET_0 will probably occur due to the non-linearity of the saturation vapour pressure - temperature relationship. Using mean air temperature instead of maximum and minimum air temperatures yields a lower saturation vapour pressure (e_s), and hence a lower vapour pressure difference (e_s - e_a), and a lower reference evapotranspiration estimate.

6.3.2.2 Relative humidity of the air (RH)

The average daily actual vapor pressure (e_a) in kilopascals (kPa) is required. The actual vapour pressure, where not available, can be derived from maximum and minimum relative humidity (%), psychrometric data (dry and wet bulb temperatures in °C) or dewpoint temperature (°C).

6.3.2.3 *Solar radiation (R_s)*

The average daily net radiation expressed in megajoules per square metre per day (MJ m^{-2} day^{-1}) is required. These data are not commonly available but can be derived from the average shortwave radiation measured with a pyranometer or from the average daily actual duration of bright sunshine (hours per day) measured with a sunshine recorder.

6.3.2.4 *Wind speed (u)*

The average daily wind speed in meters per second (m s^{-1}) measured at 2 m above the ground level is required. It is important to verify the height at which wind speed is measured, as wind speeds measured at different heights above the soil surface differ.

6.3.2.5 *Data availability in Southern Shan State*

There are not many weather stations in Myanmar able to provide public weather data, but the situation is slowly improving and more data is becoming available. For the gaps between the existing weather stations, there are plenty of online services, providing climate models with useful interpolations, which may be useful for farmers. The most important improvement in terms of weather data availability, however, was the installation of 5 Davis Vantage Pro weather stations on commercial orchards in Southern Shan State by GIZ. Weather data can be obtained from https://www.wunderground.com/. Table 5 shows the location of these weather stations.

Table 5: Location of 5 Davis Vantage Pro weather stations in Southern Shan State installed by GIZ in 2017

No.	Receiver	Console ID	Address	Latitude	Longitude
1	**U Soe Nyunt**	**AZ170123006**	Thin Baw Village , Za Lae, Aye Thar Yar	N 20° 50.855'	E 097° 00.441'
2	**U Myint Oo**	**AS160907016**	Painne Pin Village, Yatsauk	N 21° 10.654'	E 096° 56.083'
3	**U Nyi Nyi Soe**	**AS160907015**	Mangyi Gone Villate, Yatsauk	N 21° 10.152'	E 096° 47.347'
4	**U Hla Baw**	**AS160907021**	Kyan Khin Myaung Villate, Pindaya	N 21° 01.454'	E 096° 38.631'
5	**U Khun Zaw Moe**	**AZ170123016**	Naung Lone Village, Hopone	N 20° 47.180'	E 097° 13.749'

*Lists of another brand of weather station (Acurite) which were installed for Department of Agriculture are at Annex: 4

6.3.3 *Irrigation scheduling based on the climatic water balance*

As described above, the climatic water balance is used to calculate the crop water use under optimal agronomic conditions. Consequently, irrigation can be scheduled based on this data by choosing an irrigation interval and calculate the amount of water used by the crop since the last irrigation. This is the amount of water which is applied by irrigation to replenish the water storage in the soil. The choice of intervals depends – besides considerations related to the general farm management or water availability – on the water holding capacity of the soil and the crop sensitivity to drought. There is a series of computer codes published world-wide, which help to calculate irrigation schedules. Depending on data availability and equipment used, they have different advantages and disadvantages. One of the simplest programs is FAO *CropWat*, which is useful for basic climatic water balance modeling and irrigation calculation. FAO also offers the *CLIMWAT* database with long-term average data from weather station all over the world. The advanced *AquaCrop* model offers more possibilities to include plant parameters and deficit irrigation tools in the irrigation planning. All information and related programs from FAO can be accessed online: http://www.fao.org/land-water/databases-and-software/en/

6.3.3.1 Using MI-SSS to plan irrigation schemes and schedule irrigation in mango orchards in Southern Shan State

With "Mango Irrigation – Southern Shan State (MI-SSS)" GIZ has provided a mobile-phone application for irrigation planning for mango farmers in Southern Shan State. The app can be used for lay-outing of an irrigation system and for the elaboration of irrigation schedules, based on cropping and weather data. The algorithms used are the same as used in the computer code ET_0 Calculator from FAO and described in its manual (Raes, 2012). The following section provides step-by-step instructions on how to use MI-SSS.

MI-SSS presents itself as a single page calculation sheet. All areas with grey frames are input areas, where users enter values either manually or by use of steppers. Plain white fields are for calculated or output data of the application.

Field data

MI-SSS is kept simple to render approximate results with minimum data input. Thus, for field data, it is only required to enter the cropping pattern and the canopy coverage of the field, in order to calculate the amount and size of the trees. By this data, each tree is attributed a certain canopy area, which is assumed to be the transpiring surface.

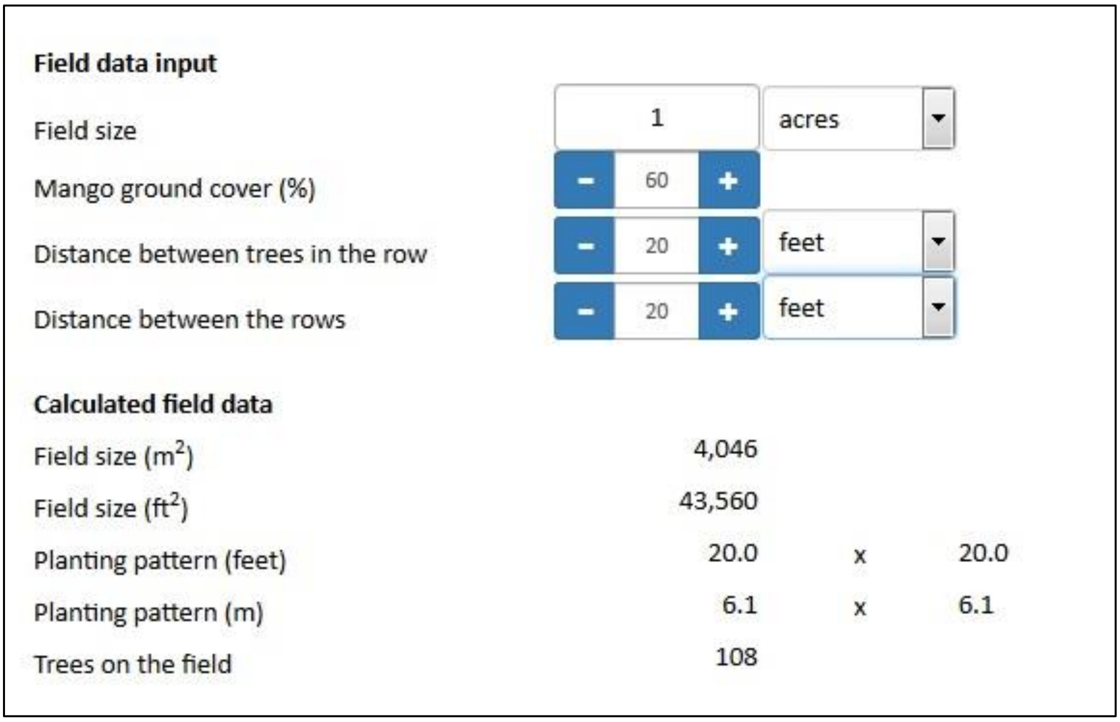


Figure 33: Screenshot of field data section in MI-SSS

As shown in Figure 33, the mango-field is characterized by its size, mango ground cover and planting pattern of the mango trees.

Note: in an intercropped field MI-SSS only calculates the irrigation requirement of the mango trees, the field size is entered manually. As unit the user may select between acres and hectares (ha). The ground cover is entered by a stepper and can be entered with an accuracy of 10%. In order to estimate the ground cover one may take the approximate canopy diameter and divide it by the diagonal distance between two trees and multiply by 100.

Example: Canopy diameter is 5 ft. and planting distance is 6 ft. x 6 ft., then the approx. canopy cover is calculated as (5 / 8.5) * 100 = 58.9 and entered as 60%

The planting distance between tree rows and between trees in the row can be entered in meters or feet with the use of steppers.

MI-SSS will then calculate the field size in m^2 and $ft.^2$, respectively, as well as the planting pattern in m and ft. and the number of trees on the field. This may not match with the real number of trees depending on the shape of the field, unplanted areas and borders. If the figure diverts too much from reality, it is recommended to adapt the field size accordingly.

Weather data

MI-SSS uses the modified Penman-Monteith equation as described in Raes, 2012, to calculate ET_o from weather data. A k_c value of 0.8, as recommended for mango (Spreer et al., 2007) is used to calculate ET_c, which is assumed to be identical with the crop water use. MI-SSS does not consider sub-optimal conditions, such as plant stress or dry soil.

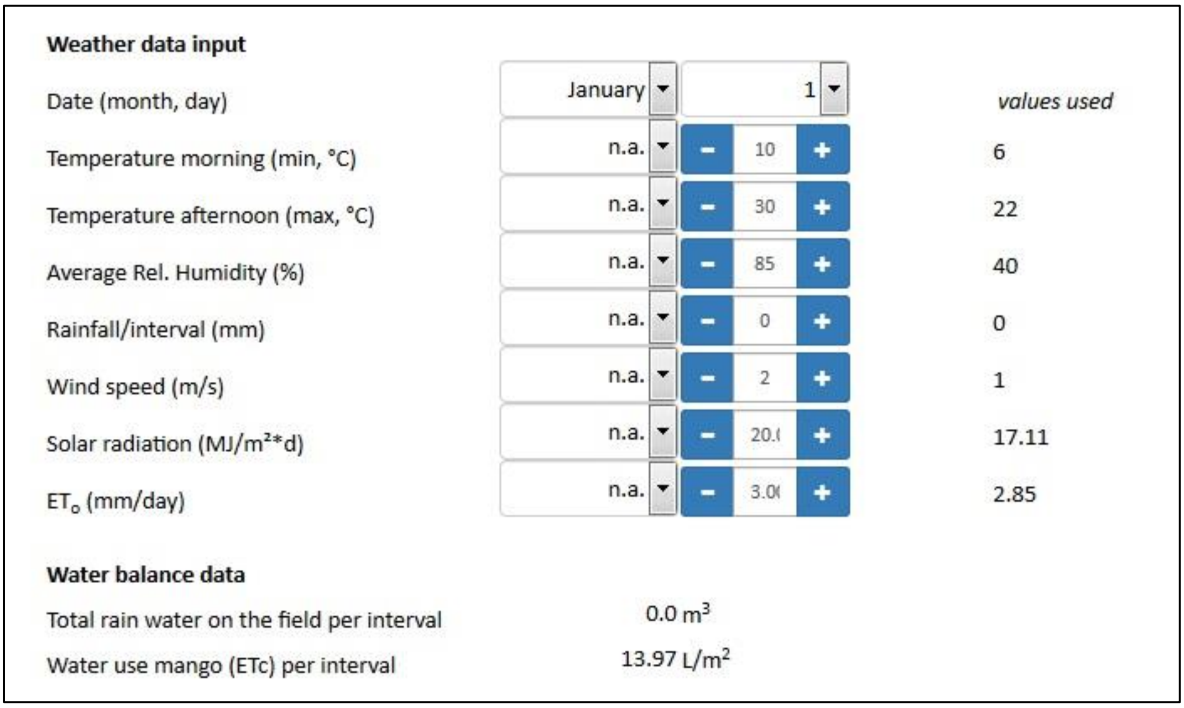


Figure 34: Climatic water balance data in MI-SSS

Date: As shown in Figure 34, MI-SSS requires a date for calculation. The date is inserted by selecting the month and the day by pull-down menus. The date is an important input if one or more parameters are not available for the calculation. In this case MI-SSS uses average data derived from a participatory climate assessment in Lawksawk in May 2013. This is rough data, but it was the only available data-set at the time of writing this manual. In the future, this data may be replaced with real data from weather stations installed by GIZ. Furthermore, the date has the function to calculate the extraterrestrial radiation, so that the program can estimate R_s, if no radiation data is available.

Temperature: Select "available" in the first box, if temperature data is available. The temperature must be input in °C. If continuously logged data is available, select the minimum and maximum daily temperature for "Temperature morning" and "Temperature afternoon", respectively. If this data is manually assessed, use the pre-dawn temperature (5.30 am) and the afternoon temperature (2.00 pm) as "Temperature morning" and "Temperature afternoon", respectively. If no temperature data is available, select "n.a." in the first box.

Relative humidity of the air: Select "available" in the first box, if relative humidity data is available. If continuously logged data is available, select the daily average relative humidity. If this data is manually assessed, use the pre-dawn relative humidity (5.30 am) and the afternoon relative humidity (2.00 pm) and enter the mean value. If no relative humidity data is available, select "n.a." in the first box.

Rainfall: Select "available" in the first box, if rainfall data is available or if the absence of rain has been confirmed. Rainfall must be entered in mm (1 inch = 25.4 mm). The value entered must refer to the cumulative rainfall between two irrigation events. This data is not used to calculate ET, but the total amount is deducted from the irrigation requirement. If there was no rainfall in the respective period, enter "0", if there is no data about rainfall, select "n.a." in the first box.

Wind speed: Select "available" in the first box, if wind speed data is available. Wind speed must be entered in m/s. Observe, that MI-SSS assumes wind speed to be measured in 2 m (u_2) height off the ground. Data collected at airport weather stations often refer to wind speed at 10 m height above the ground (u_{10}), which is often higher than u_2. If no data on wind speed is available, select "n.a." in the first box.

Solar radiation: Select "available" in the first box, if solar radiation data is available. The value entered is the cumulated daily radiation in MJ /m^2. If no data on solar radiation is available, select "n.a." in the first box.

ET_o: Select "available" in the first box, if ET_o data is available. Modern weather stations, such as the ones installed by GIZ, provide data on ET_o. Enter the value of the cumulated daily ET_o in mm. In this case none of the above entries is considered for the calculation, except rainfall. If no data on ET_o is available, select "n.a." in the first box.

Values used. On the right hand side, next to the weather data entry field, there is a list of values used for the calculation. If "available" is selected in the first box of the respective row, "values used" is identical with the input value. If "n.a." is selected, the input value will not be considered in the calculation and the "values used" may differ from the input. If "available" is selected in the first box of the row containing ET_o data, all "values used" except "rainfall" disappear, as they are no longer necessary for the calculation. Thus, data for ET_o override all other weather data.

Water balance data: Following the above mentioned, MI-SSS estimates the water use by mango trees during the interval between two irrigation events and the amount of rainfall in the same period.

Irrigation scheduling

The last part of the input refers to the irrigation planning. The user selects the “irrigation interval”, which is the interval between two irrigation events. MI-SSS does not consider soil parameters. Therefore, the irrigator must estimate and select the appropriate irrigation interval. A one-week interval is recommended for all soil types from, comprising silt, loam and clay soils. For sandy soils, shorter intervals are recommended. Refer to Annex 3 for a guide for a quick assessment of soil texture. Other than soil parameters, the irrigator should mainly consider management procedures of the farm and water availability when selecting the irrigation intervals.

MI-SSS can calculate the required time for irrigation, if the irrigation system is known. The program is designed for micro-irrigation systems with a high application efficiency. It does not consider application losses, as would arise from surface irrigation. The user can select between “drippers” and “micro-sprinklers”. The nominal flow rate is an information provided by the producer and is often evident by the name. **Example:** NETAFIM PCJ 4 has a nominal flow rate of 4 L/h and Raindrop TD70 has a nominal flow-rate of 70 L/h. Typically, drippers have flow rates between 2 and 8 L/h and micro-sprinklers and micro-sprayers 30 to 250 L/h. Micro sprinklers with very high flow rates often have a low uniformity and are not recommended for irrigation planning with MI-SSS. In MI-SSS the flow rate can be input in L/h or in gal./h. Finally, the user selects, how many emitters – drippers or micro-sprinklers – are installed at one tree (Figure 35).

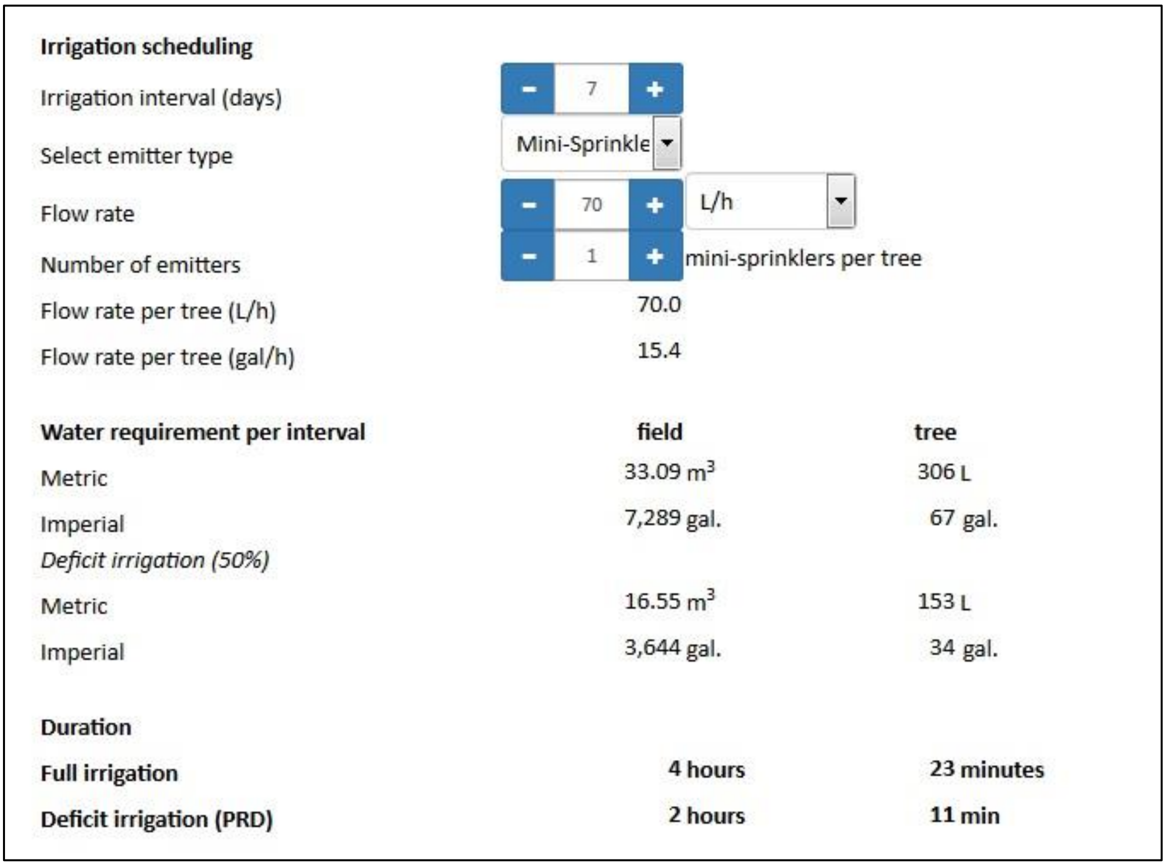


Figure 35: Irrigation scheduling data in MI-SSS

As shown in Figure 35, MI-SSS provides data on how much needs to be irrigated on the field in question. Data are given both in metric and imperial units. The data about the total water requirement during one interval can be used for the layout of an irrigation system or the consideration, as to whether a specific field can be irrigated. Taking into consideration the calculated irrigation water requirement, as well as the aspects discussed in chapter 3.2, a plan for a new irrigation system on a mango orchard can be elaborated.

For an existing irrigation system MI-SSS provides not only the amount of water to be irrigated in the selected interval, but also the time that the irrigation must be operated to apply the irrigation water. In this way, it is easy to monitor the irrigation system or have a farm manager be in charge of operating the irrigation system.

7 Fertigation

Grasses and leafy plants need to be supplied with water all the time to ensure good growth and even short periods of lack in water can lead to severe drought stress reactions, such as dropping leaves or fruit or even induce senescence. In contrast, tree crops have a larger root system and can use water of deeper soil layers and, depending on the species, have more developed methods to downregulate water consumption, by regulating transpiration and alternation in growth. Especially mango is known for being drought resistant. In agriculture, however, the scope is not on the "survival" of the crop, but on the optimal production. For this goal, the optimal supply with nutrients is often more important than adequate water supply. However, nutrients must be taken up in a dissolved form so that during dry season, broadcasted fertilizer may lose a substantial amount of e.g. nitrogen while resting on the ground before the rain falls. Therefore, the benefits of irrigating mango trees are often during the fertilization effect rather than in the sheer supply of water.

Applying fertilizer with the irrigation water is commonly known as "fertigation", which is a word composed from **fert**ilization and irr**igation**. There are different ways to use fertigation in agricultural production, which are applied according to the crop and kind of production method. Two general ways of fertigation can be distinguished:

- *Continuous fertigation* is used in greenhouses, where plants are grown in substrate. Due to the low water holding capacity of the substrate and the comparatively small root system of the plants, fertigation is applied in small amounts and short intervals (3 – 15 times per day). The nutrient concentration in the irrigation water is constant and determined by its electrical conductivity (EC) and its pH value. The actual values for EC and pH vary according to the crop and clear water is not used.
- *Field fertigation* is used in field cropping, where crops grow on natural soil. As the soil works as storage for water and nutrients, fertigation intervals are long. Most of the time, however, irrigation is carried out with clear water. According to the crop development, fertigation is applied at three to five occasions per cropping season and it is done following the same principles as fertilization by broadcasting, meaning that an amount of fertilizer per plant is calculated and dissolved in the irrigation water. Compared to broadcasting, fertigation saves labour costs and has the advantage that nutrients are already dissolved in water and can be taken up by the plants immediately.

Generally, in mango production, field *fertigation* is practiced. Thus, in this chapter, there will be no reference to *continuous fertigation*.

7.1 General aspects of field fertigation

Some important aspects of field fertigation can be summarized as follows:

- Fertilization depends on yields
- Adjust fertilization schedule according to water availability
- Fertilize after pruning with high nitrogen fertilization
- Fertilize after fruit set
- Fertilize 30 days after fruit set with high potassium
- Use manure regularly if possible (during vegetative growth)
- Soil tests are useful especially for phosphorus and organic matter determination

As mentioned above, field fertigation follows the same principles as broadcasting of fertilizer meaning that the amount of fertilizer is calculated per plant and season and then split according to nutrient composition of the fertilizer and development stage. Normally, fertigation takes place only three to five times per season. This is based on the idea to safe labor, as each fertigation event requires additional labor for transport of the fertilizer and mix it into the water. Shorter intervals are better than larger intervals, but in mango production the benefit of short intervals would be barely visible.

It is also important to see field fertigation in the context of general orchard nutrient and soil fertility management. The advantage of fertigation is the immediate provision of mineral nutrition to the trees. This way, it is possible to cover the trees' needs according to different development stages. Nonetheless, the overall soil fertility of the orchard is important to maintain at a high level. Nutrient leaching by excessive drainage and by erosion should be avoided. Mulching of surface vegetation can have a positive effect on the soil structure and soil microbial activity. Further, the application of manure provides high levels of phosphorus (P_2O_5), a plant nutrient, which can be accumulated in the soil and increase productivity on the long run. Furthermore, manure and green manure provide organic matter (OM), which cannot be provided by mineral fertilization / fertigation. Even more immediate in its action as fertigation is foliar spray of fertilizers. Besides promotion of bud break and flower induction by use of KNO_3, there is a variety of micro-nutrient cocktails on the market, which can supply important micro-nutrients, which cannot be efficiently applied to the soil. A list of important micro-nutrients, effects and deficiency symptoms is in the annex. It is important to observe that micro-nutrients are needed in very small quantities and in most cases one application per season is enough to supply this class of nutrients.

7.2 Fertigation planning

The mineral fertilization should be calculated based on the export of nutrients by harvest. In this case, ideally all nutrients which are removed from the field in the fruits, are replenished by mineral fertilizers. However, one needs to observe the management of pruned wood as well as fallen twigs and leaves. Even though, in some orchards there are positive experiences with just mulching the pruned wood, it is advisable to remove all pruned and fallen plant material and to prepare a compost *ex-situ* in order to avoid the spread of pests and fungal diseases. The compost can be re-applied to the field, but ideally, it would be applied to other fields and the nutrient and organic matter export is then covered by manure (see above).

In table xxx, there are some recommendation for nutrient application based on yield.

Table 6: Approx. nutrient removal by mango fruit harvest in [kg] nutrient / [t] harvested

Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)	Calcium (Ca)	Magnesium (Mg)
6.5	2.0	7.5	5.5	3.0

At a GIZ-organized workshop at Lawksawk (Southern Shan State), the following example for a fertilization regime was calculated based on mineral fertilizers available in this location. The regime was based on the above mentioned recommendation and shall be presented here to illustrate the calculation approach, rather than to establish a generic applicable fertilizer recommendation for mango production.

- Fertilization in quantity and timing

- Only based on chemical composition of mineral fertilizer (organic fertilizer not considered)
- Based on the assumption that the contents are as indicated
- If fertigation: Check solubility!

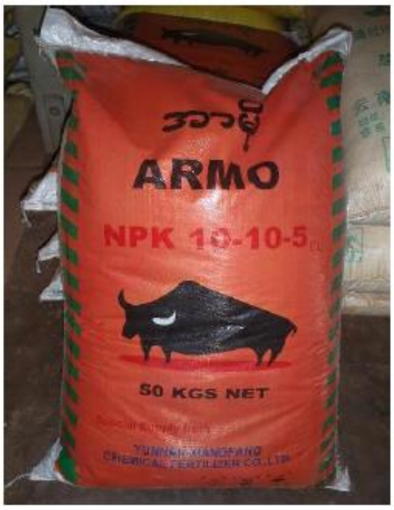
The recommendation was based on three fertilizer applications per year and the assumed removal of 60 kg fruit per tree:

1st fertilization after pruning

- Promote vegetative growth
- Supply P_2O_5 to build up fertility
- Keep N and K_2O low to avoid leaching!
- Good opportunity for organic fertilization!

Quantity calculated

- Compound fertilizer N : P_205 : K_2O = 10 : 10 : 5
- Apply on 1 kg per tree
- 100 g N, 100 g P_2O_5, 50 g K_2O



2nd fertilization with the first irrigation after fruit set

Supply N and K_2O to promote fruit growth and keep abortion low

Quantity calculated

- 300 g urea / tree 46 : 0 : 0
  - 138 g N: 0 g P_2O_5, 0 g K_2O
- 300g compound fertilizer / tree 0 : 0 : 60
  - 0 g N, 0 g P_2O_5, 180 g K_2O
- Total application
  - 138 g N, 0 g P_2O_5, 180 K_2O

3rd fertilization 30 days after fruit set

Supply N and K_2O to promote fruit growth and yield formation

Quantity calculated

- 350 g urea/tree 46 : 0 : 0
    - 160 g N, 0 g P_2O_5, 0 g K_2O
- 350 g 0 : 0 : 60 per tree:
    - 0 g N, 0 g P_2O_5, 210 g K_2O
- Total application
    - 160 g N, 0 g P_2O_5, 210 K_2O

According to this calculation, the total supply of nutrients per year and tree is as follows:

Calculation of fertilizer supply (g/tree)	**N**	**P_2O_5**	**K_2O**
1st fertilization (after pruning)	100	100	50
2nd fertilization (after fruit set)	138	0	180
3rd fertilization (30 days after fruit set)	160	0	210
Total application per year	**398**	**100**	**440**

According the calculation in Table 6 the target values for fertilization of one tree with an annual harvest of 60 kg would be 390: 120: 450. The above example would come close to these values.

A reported problem of fertigation in Southern Shan State is that some soluble fertilizers are not available, or the available fertilizers are not appropriate to use in fertigation. In the above example, fertilizers have been selected based on composition and price. They have not been tested for their applicability in fertigation. While urea is well soluble, some compound fertilizers are not. In this case, either more expensive fertilizers, special for fertigation must be used, or the fertilizer is broadcasted and then “washed-in” by subsequent irrigation with clear water. Micro sprinklers are more appropriate for this method. However, the effect is not as good as with fertigation and broadcasting implies additional labor cost.

8 Annex

8.1 Annex 1: Overview on elements in terms of plant nutrition and their impact on plant physiology

8.1.1 Macro-nutrients

- **Nitrogen**
  - Component of amino acids, protein and chlorophyll
  - Important for biomass formation
  - Deficiency: stunted growth, slow growth, and chlorosis
- **Phosphorus**
  - Component of many hormones and biomolecules
  - Important for plant growth and seed formation
  - Deficiency: intensive green, sometimes purple color of leaves, necrosis in older leaves
- **Potassium**
  - Metabolic nutrient
  - Improves plant growth, fitness and stress tolerance
  - Deficiency: Pathogens, wilting, chlorosis, brown spotting
- **Sulphur**
  - Sulphur is a structural component of some amino acids and vitamins, and is essential in the manufacturing of chloroplasts.
  - It is immobile and deficiency therefore affects younger tissues first.
  - Deficiency: yellowing of leaves and stunted growth.
- **Calcium**
  - Regulates transport of other nutrients into the plant and is also involved in the activation of certain plant enzymes.
  - Involved in photosynthesis and plant structure.
  - Deficiency: Stunting, growth disorders
- **Magnesium**
  - Constituent of the chlorophyll molecule. Promoter of enzyme reactions
  - Magnesium is very mobile in plants, and, like potassium, when deficient is translocated from older to younger tissues, so that signs of deficiency appear first on the oldest needles and then spread progressively to younger and younger tissues and is also a very important part of our body
  - Deficiency: Discoloration
- **Silicon**
  - No importance in mango production

8.1.2 Micro-nutrients

- **Iron**
  - Necessary for photosynthesis and enzyme cofactor
  - Deficiency: Interveinal chlorosis and necrosis
- **Molybdenum**
  - Required for building amino-acids
- **Boron**
  - Cell wall stability, uptake of nutrients
  - Deficiency: Stunted growth, deformation
- **Copper**
  - Important for photosynthesis.
  - Deficiency: Chlorosis
- **Manganese**
  - Photosynthesis and building of chloroplasts
  - Deficiency: Discolored spots on the foliage.
- **Sodium**
  - Sodium is not considered a nutrient in mango
- **Zinc**
  - Important for enzymes
  - Deficiency: stunted growth of leaves

8.2 *Annex 2: Weather station requirements*

Nowadays, wireless weather stations (German: *Funkwetterstation*) are widely available on the market for a variety of different uses from hobby to scientific. The general set-up is depicted in fig. 2:

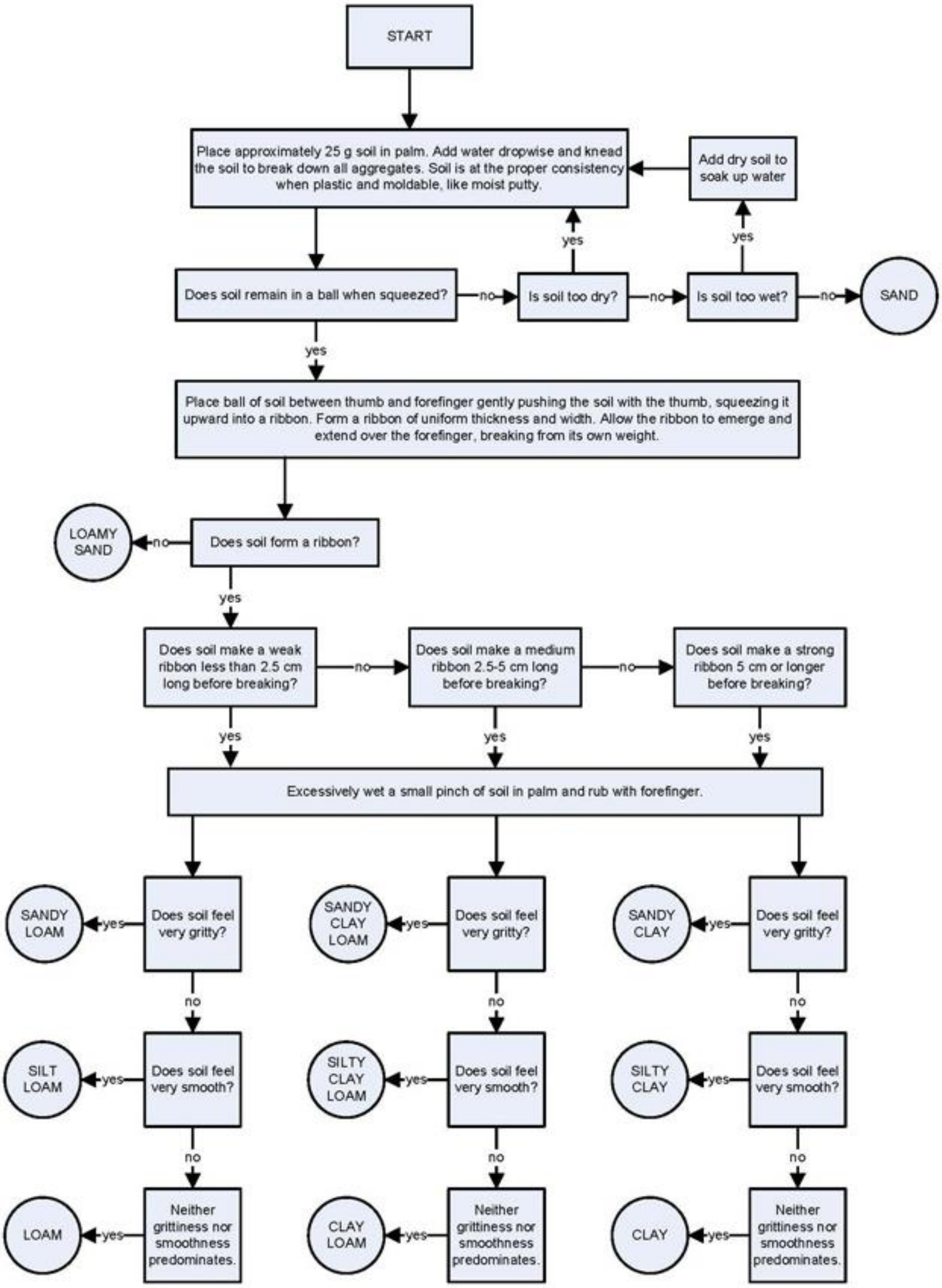
For irrigation planning it is important that the weather station features a datalogger. This can be built-in or has be bought separately. The datalogger should have a USB connection port to be connected with a personal computer or laptop. Software to read out data is necessary in most cases, depending on the format.

The sensors for **temperature**, **wind speed** and **relative humidity** of the air are simple and cheap, so that all commonly available weather stations include these sensors.

The measurement of the **global radiation** is somewhat more expensive. Therefore, several cheap weather stations do not include radiation measurements. For irrigation calculations, the radiation component can be estimated based on the position on the globe, altitude and the difference between day and night temperature. A useful alternative may be the determination of the **sunshine hours**, which can be done by a relatively cheap photocell and renders good results for irrigation calculation.

Low-cost weather stations (100 – 500 Euros) are often not made with the highest quality of materials and their lifetime may be limited. Problems with non-functioning devices may be a problem, if they are not first checked before being installed in Myanmar where there may be no technical support. Scientific weather stations generally cost more than 2,000 Euros. They are more precise, built of better quality materials and companies offer better support. The latter two aspects may be a reason for choosing a scientific weather station. In terms of precision, it is not necessary for irrigation planning.

8.3 Annex 3: Guide to Texture by Feel



Modified from S.J. Thien. 1979. *A flow diagram for teaching texture by feel analysis.* Journal of Agronomic Education. 8:54-55.

Accessed online 09/2017: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054311

8.4 Annex 4: Location of 10 Acurite and 5 Davis Vantage Pro Weather Stations in Southern Shan State installed by GIZ in 2017

No.	Receiver	Smart HUB Device ID	Console ID	Address	Latitude	Longitude
1	**Nam Kham**	**24C86E083756**	**24C86E095D2E**	Nam Kham DoA	23°50'	97°41'
2	**Nanhsam**	**24C86E0838E3**	**24C86E095DFA**	Nam Sham DoA	22°59'	89° 27'
3	**Kyaukme**	**24C86E090EF3**	**24C86E08ECFD**	Kyauk Me DoA	22° 45'	85° 23'
4	**Pindaya**	**24C86E083B81**	**24C86E096081**	Pindaya DoA	37.31'	87.56'
5	**Ywar Ngan**	**24C86E0835F0**	**24C86E096084**	Ywar Ngan DoA	26°12'	98° 55'
6	**Pin Laung**	**24C86E083B9B**	**24C86E095D6B**	Pin Laung DoA	20°12'	96°59'
7	**Yat Sauk**	**24C86E083625**	**24C86E095B08**	Yat Sauk DoA	21° 14.267'	096° 52.917'
8	**Ho Pong**	**24C86E0918B8**	**24C86E0960BF**	Ho Pong DoA	20° 47.814'	097° 10.377'
9	**Taunggyi**	**24C86E0835F4**	**24C86E095DD9**	Taunggyi DoA	20.59'	97.04'
10	**Pin Laung Tea Research Center**	**24C86E0832D2**	**24C86E095DF5**	Pin Laung Tea Research Center	20.12'	96.59'

No.	Receiver	Console ID	Address	Latitude	Longitude
1	**U Soe Nyunt**	**AZ170123006**	Thin Baw Village , Za Lae, Aye Thar Yar	N 20° 50.855'	E 097° 00.441'
2	**U Myint Oo**	**AS160907016**	Painne Pin Village, Yatsauk	N 21° 10.654'	E 096° 56.083'
3	**U Nyi Nyi Soe**	**AS160907015**	Mangyi Gone Villate, Yatsauk	N 21° 10.152'	E 096° 47.347'
4	**U Hla Baw**	**AS160907021**	Kyan Khin Myaung Villate, Pindaya	N 21° 01.454'	E 096° 38.631'
5	**U Khun Zaw Moe**	**AZ170123016**	Naung Lone Village, Hopone	N 20° 47.180'	E 097° 13.749'

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