Drip irrigation for smallholder farmers

A review of literature and current projects

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WAGENINGEN UNIVERSITY & RESEARCH

Rijksdienst voor Ondernemend Nederland

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For the Netherlands Enterprise Agency / de Rijksdienst voor Ondernemend Nederland (RVO)

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The Netherlands Enterprise Agency is a department of the Dutch ministry of Economic Affairs and Climate Policy that implements government policy for Agricultural, sustainability, innovation, and international business and cooperation. NL Enterprise Agency is the contact point for businesses, educational institutions and government bodies for information and advice, financing, networking and regulatory matters.

Photo cover: Water filter of drip irrigation kit demonstrated at experimental fields of Adami Tullu Agricultural Research Centre, Ethiopia (March 2020, Acacia Water)

Contents

1 Introduction

This document aims to **provide a framework and a common vocabulary about drip irrigation interventions**. It is written for the Netherlands Enterprise Agency (Rijksdienst voor Ondernemend Nederland, RVO), to assist in supporting projects in their portfolio that engage with drip irrigation, either as a core activity or more indirectly. The document raises important points for discussion and consideration, in the first place for implementers of RVO projects, but it also provides useful information for RVO project advisors as well as for policy makers in this field of work. The document is certainly not a blueprint for 'how to do drip irrigation for development', though the text does provide references to balanced practitioner publications that reflect on state-of-the-art implementation practices and aim to provide practical and strategic suggestions for implementers. These are also listed in Annex 3, which contains suggestions for further reading.

1.1 RVO portfolio and processes

The main scope of RVO is to implement government policy frameworks. Within the context of this review, particularly it concerns three programs of the Ministry of Foreign Affairs (MFA): FDOV, SDGP, and FDW. In these programs RVO manages the provision of subsidies to Public Private Partnership (PPP) projects in the Global South that support development objectives while operating on a viable business strategy.

Current programs with PPP projects involving drip irrigation:

FDOV: Facility for Sustainable Entrepreneurship and Food Security

SDGP: Sustainable Development Goals Partnership facility

FDW: Sustainable Water Fund

The three MFA programs that contain projects that engage with drip irrigation generally aim for the commercialization and intensification of agriculture in the Global South. Cash crops are being promoted, as well as the development of agricultural processing chains. Often, (drip) irrigation implementation serves as a supporting tool in these agricultural intensification projects, the extent depending on the project goals. **In some projects, drip irrigation is replacing existing (surface) irrigation systems, while in other cases irrigation is being developed from scratch**, shifting from rainfed to irrigated agriculture.

1.2 Methodology

In preparation for writing this document we have reviewed the project plans of 14 current projects, selected by RVO. Annex 1 contains a list of the projects, each with a short summary of the project and how it deals with (drip) irrigation. We interviewed the current RVO project advisers for these projects and by email we sent a short questionnaire to the project implementers of these 14 projects. As authors we have used our existing knowledge of the field of work and its literature to distill core knowledge and insights that are useful for the described audience and RVO program. We refer to the original literature where we think this could be useful as further reading, while aiming to be concise in our writing.

1.3 Structure of this report

In the next section we describe and discuss the main objectives that drive drip irrigation development worldwide. In section 3, 4 and 5 of this document, the challenges and considerations around drip irrigation are explained from field level, system and catchment level, and sector level perspectives. Chapter 6 concludes with some of the main dilemmas and tensions that surround drip irrigation implementation. Three Annexes provide background information that may be of interest to some of the readers. Annex 1 is an overview of the 14 PPP projects reviewed. Annex 2 contains a description of three important agricultural water use indicators and a discussion of the implications of using these for monitoring of impacts of drip irrigation projects. In Annex 3 an annotated bibliography is provided, listing several practical guides, technical documents and opinion pieces. For each we describe in one or two sentences why these are of interest for further reading.

2 Objectives of (drip) irrigation projects

Irrigation is the process of supplying water to plants, in places where rainfall does not meet the crop water requirements. Therefore, irrigation can make agricultural production possible in places where rainfed farming cannot take place, it can provide an answer to variability in rainfall, and it can prolong growing seasons. Consequently, irrigation is globally one of the main factors in pushing agricultural development. Irrigation played an important role in the Green Revolution, which greatly boosted agricultural production around the world, and particularly in Asia, in the 1950s and 60s. Nowadays (improved) irrigation practices are being considered an essential component of improving the worlds' agricultural output in order to cope with population growth and changing diets.

Several types of irrigation exist, with the main categories being; surface irrigation, localized (drip) irrigation, and sprinkler irrigation. Within these main categories a high diversity in technologies and practices can be found, often very context specific. Drip irrigation is often promoted as an improved irrigation practice, largely within policies and projects that are related to the Sustainable Development Goals. The **three main objectives used in promoting drip irrigation** can be identified as; **conservation of water, improving productivity, and alleviating poverty**. The different ways of framing depend on the context and the actors involved (policymakers, international donors, governmental agencies, private companies, farmers etc.) (Kuper, Venot & Zwarteveen, 2017). Drip irrigation is not the only tool or technology that can obtain these objectives. Therefore a thorough problem analysis should take place before implementation. One of the main pitfalls in promoting drip irrigation, and any technology for that matter, is the 'one solution fits all' principle.

We elaborate on three main objectives that frequently underpin drip irrigation projects and programs, and indicate some points of attention for each of them.

2.1 Objective 1: conservation of water

The conservation narrative relies on the efficiency increasing potential of drip irrigation, and is pushed by irrigation engineers and scientists. On field level, drip irrigation can have an application efficiency of 90-95%. This is a lot higher than more traditional irrigation techniques, that range from 40-60% for surface irrigation, and 75% for sprinklers (Brouwer et al, 1989). Therefore it is often claimed that drip irrigation could help solving the water crisis, by reducing irrigation 'losses' at field level. Although promising, **the indicated efficiencies will not automatically occur in the field**. These numbers are often based on 'best practices' obtained under experimental settings. Not all farmers will be able to obtain these results in the field, a badly managed drip irrigation systems could therefore have a lower efficiency than a well-managed surface or sprinkler system. This should be a consideration when promoting drip irrigation. Will the farmer be able to obtain the results needed in terms of 'water saving'? Or would it be easier to improve the irrigation techniques a farmer is already using?

In some of the PPP projects assessed, drip irrigation is replacing traditional rainfed (non-irrigated) farming systems. Here the conservation narrative will not apply, and water application will by definition increase in comparison to previously existing practices.

In assessing efficiencies and losses it is very important to have clarity about which (part of) a system is being studied. **What is considered a water saving at field level, might not be a water saving when observed from a basin scale**. The best way to illustrate this is by using an example: If 10 m^3 is pumped up and 8 m3 of this reaches the fields, the *efficiency* of the canal system is 80% (see figure 1 below). If of the 8 m^3 that is put onto a field 4 m^3 ends up the rootzone of the soil, the *efficiency* of this water application is 50% (4 divided by 8). The overall *irrigation efficiency* from pump to root zone is 40% (4m^3 of the 10m^3 pumped up).

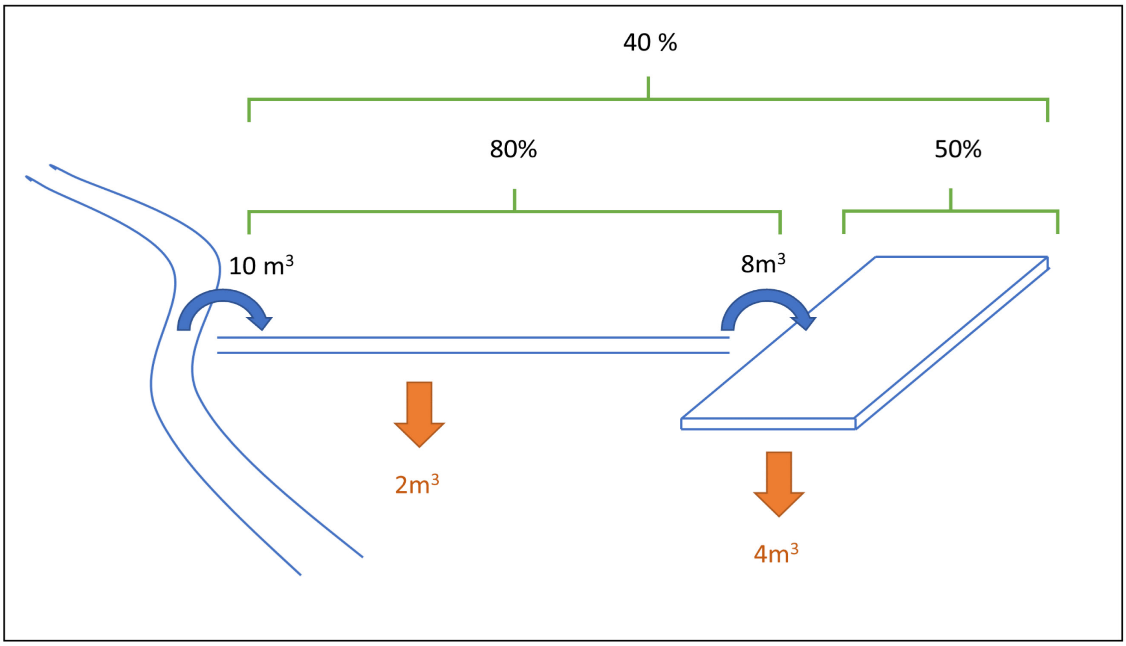

Figure 1 *Schematic representation of an irrigation system and calculation of efficiencies (explanation in the text immediately above)*

Furthermore it is very important to know what happens with the water that is 'lost'. The water that does not reach its destiny is technically considered a loss (the red arrows in figure 1). The 2 m^3 that were lost from the canal and the 4 m^3 that did not end up in the root zone of the field may have flowed down to the next farmers field and may have been used there. Or part of it may have percolated so deep that the crop cannot reach it, but where it does contribute to ground water recharge. Both the next farmer and the users of the groundwater value the 'losses' as a resource. Improving *irrigation efficiencies* entails reducing 'losses'. Fixing leakages in the canal may reduce the losses from the canal, but this may actually imply that others lose it as a resource. It is therefore useful to make a distinction between losses that are recoverable for other use and non-recoverable losses (Lankford, 2006).

Therefore, **irrigation practices that have a high *efficiency* are not per definition good for other users**. Improving *irrigation efficiency* does not per definition increase water availability for others, because of losses that can be return flows but also because a higher efficiency does not imply less water abstraction. This is also referred to as "dry" and "wet" water savings, where the latter indicates a water saving that makes water available for other uses and the former a saving that is used at the place where the saving was made and thus does not become available elsewhere in the basin (Seckler, 1996).

2.2 Objective 2: increased productivity and agricultural modernization

The promise of an increase in productivity is often connected to the analysis of a global food crisis. This is a shared element with the water conservation objective. Water use is connected to food security, as in many situations water is one of the main constraining factors in food production. In order **to deal with global population growth, more food has to be produced with the same amount of water, i.e. we need more crop per drop**. Farmers play a central role in this objective, since they have to carry out the water productivity improvements on their farm. Drip irrigation can be an important tool in this process, since it allows for the cultivation of other crops, with a different timing in the season, and potentially a higher (more uniform) quality. Although reaching this objective depends on individual farmers, the objective of increasing water productivity is often pushed as part of governmental programs or part of NGO’s projects.

2.3 Objective 3: poverty alleviation and development

Drip irrigation provides farmers with options to cultivate other crops, and at a different time of the year, since they are not dependent anymore on the irrigation system or on rainfall patterns. Development workers and drip irrigation manufacturers have pushed this as an agricultural revolution since the early 2000’s. **As a result of water efficiency and water productivity increase (objectives 1 and 2), income increase and poverty alleviation could take place**. In order to make this possible for smallholder farmers who cannot afford conventional drip systems, low cost drip kits have been developed. These are small scale and expendable forms of drip irrigation. The underlying idea being that when smallholders are supplied with the right technology, they can make their way out of poverty. They could do so by exploiting the new cultivation options the drip kits offer. This assumes however that all farmers have the skills to be innovative, entrepreneurial and market driven (Kuper, Venot & Zwarteveen, 2017). Farmers sometimes lack these skills, and even within target groups large differences can occur between farmers. We elaborate on this in chapter 5.

2.4 Objectives and monitoring

As the narratives around drip irrigation are diverse, so are the objectives of the projects aiming to introduce drip irrigation. Distinguishing between these three broad objectives may be helpful in dissecting the sometimes subtle differences in objectives between water productivity increases and saving water to become available for other uses. In Annex 2 an overview can be found on how to think about water use and water savings in relation to the introduction of drip irrigation. Here also an explanation can be found of the main indicators that are used to quantify good agricultural water us. In relation to the objectives of development and poverty alleviation drip irrigation has a very different role, and indicators like work load reduction and income increase become relatively more important for monitoring impacts. These broader aspects are discussed in chapters 3 and 4, which are respectively about drip irrigation at field level and at system and catchment level.

3 Drip irrigation at farm and field level

The implementation of drip irrigation has a wide variety of implications and challenges on the field or farm level. As described in the preceding chapter governments and water managers often consider the shift to drip irrigation from a perspective of water saving, agricultural productivity or development. Individual farmers however, often have very different reasons to adopt drip irrigation. This chapter presents, from a practical point of view the advantages, disadvantages, challenges and strategies as experienced by farmers.

3.1 A farmer’s perspective

From a farmer’s point of view, implementing drip irrigation can be interesting for a number of reasons. First of all**, it provides the possibility to precisely provide water to the plant**, the right amount at the right time. Compared to rainfed agriculture this offers more control, creating the opportunity to cultivate a broader range of crops, independent from the rainfall conditions. Compared with surface irrigation systems, drip irrigation offers a higher degree of control and flexibility, again creating the possibility to cultivate a broader range of crops, expand cropping season and increase crop yields. For surface irrigation nearly levelled field conditions are needed to distribute water by gravity forces. Drip irrigation can be applied under slight sloping conditions. It may therefore also increase irrigated area since drip irrigation allows to expand to sloping landscape formerly not suitable for irrigation. Secondly, **drip irrigation can reduce labor requirements**, since it can be highly automated. Farmers do not have to be in the field to manually guide the water or open their canal intakes. Thirdly, **drip irrigation systems allow for the application of fertilizers together with the irrigation water**, a process called fertigation. This further reduces labor requirements, as it combines adding water and fertilizer at the same time while improving crop production. Fourthly, **drip irrigation conveys the message of modernity**. If a farmer has a drip irrigation system, he belongs to the ‘modern’ and ‘clean’ farmers. Whereas surface irrigation can be seen as a ‘backward’, ‘old fashioned’ and ‘dirty’ practice (Van der Kooij et al., 2013; Benouniche et al., 2014). This can be a major driver for drip irrigation implementation, especially for young farmers.

The implementation of drip irrigation however, is not a simple process for farmers, with several challenges related to investments, knowledge and operation of the systems.

3.2 Investments, returns and risks

The implementation of **drip irrigation technology requires relatively high investments**, even when considering low-cost options. Twelve out of the fourteen FDOV, FDW and SDGP projects investigated mentioned the high cost and the lack of credit support as a major issue in the adoption of drip irrigation in the project. Since drip irrigation is often installed at farm or field level, these investment costs usually have to be carried by the individual farmer. This requires an investment rationale, which is unfamiliar to most smallholders. The project *Increasing water use efficiency in sugarcane growing India* (FDW14IN20) gave a critical role to financial literacy education. The return on investment to the farmer has to be very clear and it requires a proven business case that demonstrates the financial gains that can be made by adopting drip irrigation. Especially in places where drip irrigation is replacing surface irrigation, it requires a major shift in both farming practices and irrigation management. Investments in surface irrigation usually come from government bodies, and farmers pay a relatively small fee to use the systems. Drip irrigation systems on the other hand are usually financed by farmers themselves. Thus in order to facilitate the transition, farmers need access to sufficient capital, either from their own reserves, or provided by external parties.

Combinations, where farmers provide part of the capital themselves, while the other part is covered by government subsidies, are a common practice (Merrey and Lefore, 2018; Otoo et al., 2018).

Along with the change of irrigation technology, a change in crop type (or cropping strategy) often occurs, as under drip irrigation farmers are often free to choose their own irrigation schedule, making it possible to cultivate crops that were not possible under rainfed, or surface irrigation conditions. When changing from rainfed to irrigated production this often entails **a move from staple to horticultural crops**. In any case farmers need to opt for *commercial* crops in order to generate enough return on investment. For many smallholder farmers the introduction of drip irrigation often requires a big step towards producing for the market. In various FDOV, FDW and SDGP projects there is attention for crop diversification and improving nutrition and although vegetable production might increase it does not automatically lead to improved nutrition for the farmer's family as products need to be sold as part of the value chain of buying inputs and selling outputs. Next to an investment in drip irrigation infrastructure, other agricultural inputs are needed for commercial production processes. For instance new seed varieties, pesticides, plastic mulch, and chemical fertilizers. The extra inputs add to the investments that have to be made by the farmer, and are annually recurring. Furthermore, **the production of higher value, commercial crops, requires a different way of farm management**. When farmers switch from subsistence production, or producing for local markets, to full-scale commercial production demands from wholesalers and retailers start to have an influence. These parties can set requirements for crop types, crop quality and crop uniformity which farmers have to meet. The introduction of drip irrigation can therefore be an important factor in changing the organization of agricultural production systems in its entirety.

Beyond the monetary investments that are required to facilitate the transition to drip irrigation and commercial crops, it requires a major shift in skills and knowledge. Smallholder farmers have to gain a whole array of new skills, ranging from operating the drip irrigation system and tending to a delicate crop, to trading their product on (inter)national markets. Social networks play a crucial role in acquiring these new skills. Without the access to the needed social networks, it can be impossible to buy the right inputs, to acquire the operational skills for the drip system, or find the right market connections.

High investment commercial agriculture, is often associated with richer farmers. They already have the (financial) starting position that facilitates their transition to drip irrigation. These farmers are often also connected to different and wider social networks, providing them with better connections to markets and input suppliers. Furthermore, commercial agriculture is associated with male farmers, whereas the female farmers are more associated with the home gardens. Out of the 14 reviewed RVO project 4 projects explicitly mention the role of female farmers in the project. However, it is unclear what the impact is and how women are specifically involved in the introduction of drip irrigation. Research in Zambia revealed that the poverty impacts of low-cost drip irrigation technologies are potentially skewed, favoring the intrahousehold bargaining positions of men and make it more difficult for women to derive benefits from low-cost irrigation technologies broadly (Veldwisch et al. 2017). This complicated set of requirements to make drip irrigation and commercial agriculture possible runs the risk of becoming an obstacle for a large number of farmers, while a selected few other farmers can benefit, thus potentially increasing socio-economic differentiation among farmers. Moreover, farmers that do engage in an investment, but do not manage to produce sufficient returns on investment run the risk of getting stuck in substantial debts.

3.3 Design and operation

The operation of a drip irrigation system can be a challenge, and requires new skills. The system has to be well designed and operated, in order to achieve the promised results related to crop quality and quantity. **The design of a system can have major influence on the performance**, especially in low cost, non-pressure compensating systems. If the field is not properly levelled for instance, large differences in discharge can occur between the emitters. This will result in a lower crop uniformity over the field, while at the same time increasing input use and pumping costs.

Although a drip irrigation systems have the potential to provide exactly the amount of water that the crop needs in different growth stages, it needs **new skills for the farmers to adequately schedule the water application**. Many farmers lack the tools and support for proper scheduling, resulting in either over- or under-irrigation during parts of the growing cycle. The project about *Increasing water use efficiency in sugarcane in India* (FDW14IN20) has the experience that farmers switch on their pumps for drip irrigation as they were used to do under surface irrigation circumstances since they lack the knowledge to determine accurate irrigation scheduling for the new drip irrigation equipment. Although the technology is presented on demonstration plots, the long term training and extension services is often lacking in many project situations.

The quality of the drip irrigation systems is often an issue, especially for low cost options. Bad experiences with low cost drip systems in the past biased farmers in the Drops4Crops (FDW16074BF) project in Burkina Faso. Some of the drip tapes only last for one irrigation season, since they easily degrade under influence of the sun. The resulting pile of plastic waste is often burned since no recycling options are present. Furthermore, the low quality of the tapes requires a seasonal investment in new materials, creating an additional input cost in the production process.

Another important aspect to consider in the operation of drip systems, is the filtration of the irrigation water, before it enters the system. The type and intensity of the required filtration depend on the local conditions and the water source. The common minimal filtration is the use of a mesh or sand filter. When the water is not filtered properly, it can **easily clog the drip emitters**. In some situations chemical additions have to be used to flush the emitters. Regular maintenance and cleaning of the filters is key to proper use of the drip system. Seven out of 14 of the FDOV, FDW and SDGP projects reviewed mention maintenance and clogging issues as important limitations in project implementation.

Since drip irrigation is pressurized it requires pumping. Water can be directly pumped from a (tube)well into the drip system, which is common practice in the high technological systems. The introduction of (tube)wells and drip irrigation are often combined. Another possibility is to pump from ground or surface water, in a storage tank, which further releases the water into the system, providing pressure by using the elevation of the water. This last practice is common in low-cost drip kits. In any case, **pumping requires substantial energy, which can form a major part of the operational costs of drip irrigation systems** (Berbel et al., 2015).

4 Drip irrigation at system and catchment level

The considerations and challenges around drip irrigation implementation are highly scale specific. Therefore the considerations change when zooming out from field to catchment level. When farmers install small drip systems on their individual fields the effects add up at catchment level. In other situations drip irrigation may not be installed individually, but as larger systems, supplying hundreds or even thousands of farmers through pipes under water pressure.

4.1 Catchment level effects

The cumulative effects of introducing drip irrigation can be seen at catchment and basin scale. To what extent, when and where these effects are experienced is very context specific. For instance, is drip irrigation replacing surface irrigation or is it new irrigation? In what season is irrigation taking place? What are the water sources being mobilized? Stimulating drip irrigation requires a careful water system analysis to be able to monitor and evaluate such effects. See Annex 2 for a discussion of relevant indicators and considerations regarding practical issues in monitoring.

4.2 Pressurized pipe systems

Increasing the size of a drip irrigation system from a single field level to a larger area (for instance several fields or farms), increasingly complicates the design, construction, maintenance and management of these systems. These **larger drip systems require higher pressures**, since water has to be transported over longer distances. The higher pressures **imply higher pumping and operation costs, adding to the overall investments**. Furthermore, in the larger systems it becomes increasingly difficult to supply all the parts of the system with the same pressure and therefore the discharge of the emitters becomes more variable. In turn, this can lead to higher water use, and lower crop uniformities especially in cases where fertigation is used. Systems have to be checked for breaks and leakages on a regular basis, which also requires a larger labor input with increasing size of the drip system.

For many of these larger systems, **it is not realistic that farmers, or farmer organizations, manage these themselves**. Technicians and specialized companies have to be hired to provide operation and maintenance services. This creates a new mode of farming, where certain activities are left to service companies, instead of a (smallholder) farmer who takes care of all the farm activities.

In many cases the introduction of drip irrigation is combined with the development of (tube)wells. This allows farmers to tap into a water source that is readily available. At the same time, farmers can hold on to their surface water rights, causing their overall water usage to increase. Intensification of ground water use can cause lowering of the groundwater table and this may also impact the availability of surface water. This can affect the management and operation of surface irrigation systems, and increase competition between farmers that started pumping water and those that do not. The Food for All Project in Kenya (FDOV14KE63) has a clear objective in increasing agricultural production in a water scarce area. The transformation from rain seasonality to drip irrigation increases the pressure on the limited water resources. The unreliable water supply and water availability reduces the enthusiasm of farmers towards adopting drip irrigation. It might also result in competition with other water uses. The Access to Sustainable Markets and Food Security for Nicaragua’s Coffee and Cocoa produces (FDOV12NI01) reports on conflicts on water sources among users and competition on drinking water supply.

Furthermore, drip irrigation allows for agriculture on lands where this was previously not possible. It creates the ability to start irrigating marginal or sloping lands (Cornish, 1998; Garb & Friedlander, 2014). Therefore, **the cultivated area can grow after implementation of drip irrigation**, especially in places where land availability is not a restrictive factor. While this benefits the individual farmers, **it can cause a decrease in water availability elsewhere in the river basin**.

Drip irrigation implementation on the largest scale concerns the conversion of entire surface irrigation systems into pressurized systems. In these systems the entire water delivery network is pressurized, up to the farm outlet, where drip lines can be connected. Conversion of open canals systems to pressurized networks is mainly done from a water saving perspective. Furthermore, it allows for easy water metering on a large scale. On-demand management is often part of these networks as well, where farmers can place a water order with the system management.

However, where pressurized networks are introduced in overlap with an existing surface irrigation system, hybrid systems emerge. This complicates operation and maintenance, water distribution and fee collection. When not properly managed, this can cause conflicts over water distribution and maintenance issues between farmers that are connected to the pressurized network, and farmers that only use the surface system.

5 Strategies for sectoral support of drip irrigation

At sector level a major challenge, especially in developing countries, is the availability of drip irrigation equipment. Often, there is no local production of drip irrigation equipment taking place. The market is controlled by a few large scale international producers (Netafim, Jain, Rainbird, Rivulis). **The price of the equipment is therefore heavily influenced by import tariffs, and transportation costs make up for a large share of the price for farmers**. At local agro-dealer shops the equipment availability is often low, and parts have to be brought in from the capital. When parts break at a crucial moment during the growing season, and farmers have to wait several days for the right part to arrive, this can seriously harm their production. In some cases where no spare parts were available, or systems were not meeting local conditions, local farmers and engineers started making their own spare parts and adaptations to the systems (Benouniche et al., 2014). Networks of local technology providers can play an important role in making drip irrigation and spare parts available locally. Supporting local agro-dealer shops in having suitable and sufficient (drip) irrigation materials on stock can be helpful in developing the sector. This includes **facilitating linkages between importers and national producers on the one hand with sales networks on the other**. There are positive experiences the set-up of Smart Centres (SCs) in which training, demonstrations and trials are carried out. The SCs can also be places to organise open field days and knowledge sharing events by NGOs, agricultural extension services and technology suppliers (SNV, 2019a).

Next to the parts itself, **the provision of the right services and support should be an integral part** of drip irrigation implementation. Advice should be available on which parts to use for a certain system, and quality control on the systems and spare parts should take place. However, this is often not the case, since knowledge in the form of qualified personnel is limitedly available in rural communities. For support and service drip users often have to rely on the advice of irrigation suppliers who also often have a commercial interest. **Improved coordination between different kinds of actors involved in irrigated agriculture may help to overcome challenges** that individual organizations fail to address. There are positive experiences with setting-up multi-stakeholder platforms specifically to support smallholder irrigation development, for instance in the Smart Water for Agriculture project in Kenya (SNV, 2019b).

Next to drip irrigation, other technologies exist that could improve on farm water use (e.g. micro sprinklers, improved furrow practices, soil moisture management). These could provide viable alternatives to drip irrigation, and should be considered before starting the drip implementation process. Especially since appropriate technologies should be matched with different farmer types. In the *Improved Water Allocation and Irrigation Efficiency in the Ziway-Shalla Basin project* (FDW17072ET) is the option being discussed whether simple improved surface irrigation practices might be preferred over introduction of a new drip irrigation technology in order to decrease the water demand of agriculture in the area.

Drip irrigation projects often roll out the implementation by using lead farmers and / or pilot plots. A fair number of FDOV and FDW projects implement drip irrigation demonstration sites. The idea behind it being: if the pilot farmers can adopt the technology, adoption should be possible for other farmers too. They consider the technology to be a fundamental solution that with the right support, training or financial resources, will work for all smallholder farmers.

This is based on assumption of relative homogeneity among farmers, or at least within farming categories. Farmers are often grouped on value chain, scale or income levels. Large differences can however exist between the highest and lowest ranking farmers within this category. Differences for instance related to crop type, production systems, income, and gender. The logics of the agricultural production processes can hugely differ, greatly influencing what is a fitting technological improvement. If drip irrigation functions on the field of the lead farmers this does not necessarily mean it will be attainable for all the other farmers, not even if they are broadly from the same category. Beyond the question whether farmers have **knowledge** of drip irrigation it is also important to know whether they have the **ability** and **motivation** to implement it. Does the technology work well in farmers' situation? Are they capable of using it? Can farmers access and buy the technology? And can they manage the implications (ability to market and recover investment costs)? Do farmers assess that the technology is worth adopting? How do the burdens/costs of using the technology compare to benefits obtained? What are and how do farmers perceive the risks involved? Strategies for promoting drip irrigation at scale need to address these questions of ability and motivation, i.e. they **need to assess how drip irrigation may fit in the context-specific realities of different farmers**.

6 Interests and Dilemmas

Looking back to the described objectives and impacts on field, system and sector level, a few tensions or trade-offs can be identified. Being aware of these trade-offs can assist project advisors and implementers, in making deliberate choices around project activities and objectives.

Within each of the three main objectives of drip irrigation project and programs (water conservation, increased productivity & poverty alleviation) several tensions can be identified. For instance, **what if drip irrigation increases the quality of production but does not decrease water consumption**? Or increased production and intensification takes place in one area, which in turn leads to farmers expanding their business and increasing their water use, to the detriment of water availability elsewhere? Or increased production occurs, but does not lead to poverty alleviation, since more investments and inputs are needed to operate the drip systems? These tensions show the importance of considering the possible impacts of drip irrigation beyond the scope of the project, or outside the project area.

Furthermore, a tension might occur between the project objectives, and the reasons for farmers to adopt drip irrigation. Important reasons for farmers to adopt drip irrigation include a decrease in labor requirement, the possibility of fertigation, independence and an appearance of modernity, yet these are generally not considered in project objectives. Therefore, even when farmers adopt drip irrigation, **targets for water conservation or increased production might not be reached, since farmers had very different considerations for drip adoption**.

For farmers to change to drip, requires intensification and commercialization of the agricultural system, which is only possible with an investment rationale, connecting to the market and the whole value chain of production. This requires a major development in skills and knowledge far beyond the drip technology alone and should therefore be an important part of the project implementation. Heterogeneity in terms for crop type, access to the market, income and gender between farmers greatly influencing the appropriateness of the technology and the services and advice provided. If these differences are not sufficiently dealt with during project implementation, they can enlarge the differences between farmers.

Drip irrigation technologies indeed offer the possibilities of providing water to plants in precisely the right amount at precisely the right moment. Whether farmers are interested and able to use drip irrigation technologies depends on a wide variety of context specific factors that range from cultural to organizational and from technical to economic. **Farmers' adoption of drip irrigation may indeed contribute to broader societal objectives of a fair water distribution, economic development and prosperity, but it is certainly not guaranteed and often beyond the control of project interventions**. Annex 2 contains a more detailed discussion of relevant indicators and practical considerations to monitor such effects.

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Annex 1 Reviewed RVO projects

More information on the projects can be found on the RVO project database:
https://projects.rvo.nl/section/development-cooperation/?programmes=2833

	Programme	Project name	Country	Project purpose and role of drip irrigation
1	FDOV (12NI01)	Access to Sustainable Markets and Food Security for Nicaraguas Coffee and Cocoa producers.	Nicaragua	The purpose of the project is to increase the income, improve food security and living conditions of 5000 small coffee and cocoa producers. This done through access to markets, improvement of organization's management, technological innovation, product diversification and education. The use of drip irrigation is at a small scale and not a focus point of the project
2	FDOV (12TZ01)	"SEVIA" Seeds of Expertise for the Vegetable Industry of Africa	Tanzania	The project is aimed at contributing to food security strategy and vegetable industry development for Africa by providing adapted varieties and setting up an African Institute for Vegetable Technology. This institute should boost the development of farm innovations and screening of genetic vegetable resources for Africa. Drip irrigation is one of the farm innovations to improve water use efficiency.
3	FDOV (14ET01)	Fair Planet five year plan for Ethiopia	Ethiopia	The project goal is to empower smallholder (women) farmers and improve economic agriculture by providing them with affordable seeds, entrepreneurial training and marketing opportunities. Training is provided on improved irrigation including the use of smallholder drip irrigation kits on a limited scale.
4	FDOV (14KE63)	Food For All Project in KENYA (F4APK)	Kenya	The project aims at improving food security by increasing agricultural productivity through introduction of improved technologies. Drip irrigation, being one of the innovations, is promoted through practical training on demonstration plots.
5	FDOV (14GT03)	Every bean has its black	Guatemala	The project goal is a sustainable impact and inclusive economic growth for Guatemalan small-scale vegetable farmers in the highlands. This done by providing sustainable technology packages which include, among others, improved irrigation technology like drip and sprinkler irrigation.
6	FDW (14IN20)	Increasing water use efficiency in sugarcane growing in India	India	The purpose of the project is to enhance sustainability of sugarcane growing and raise smallholder incomes by introducing water efficient practices at the farm level and achieving sustainability on a clear business case for farmers. Drip irrigation is introduced to address the over-exploitation of groundwater and provide higher yield and income for the farmers
7	FDW (14SA19)	Reducing the water footprint of sugarcane smallholder producers	South Africa	The objective of the project is to increase the irrigation efficiency in smallholder sugarcane based cropping systems. Drip irrigation is promoted to improve yield, reduce costs of production and improve resilience against negative impacts of climate change. Drip irrigation is implemented through pilot sites and bulk infrastructural adjustments to permit effective conversion to drip irrigation.

	Programme	Project name	Country	Project purpose and role of drip irrigation
8	FDW (16074BF)	Drops4Crops	Burkina Faso	The purpose of the project is to implement integrated water resources management measures and efficient water use for off-season horticulture production by smallholder (female) producers. This is done through providing credits for investment in water-efficient technology, climate smart agri-training and secured land access. Drip irrigation, among other irrigation technologies, is promoted through demo sites.
9	FDW (17074BJ)	Drops4Crops	Benin	The aim of the project is to improve the efficiency of water use for vegetable production through irrigation equipment, solar pumps and water storage in order to generate a sustainable income for the (female) farmers. Innovative water technologies are promoted through demo sites.
10	FDW (17072ET)	Improved water allocation and irrigation efficiëncy in the Ziway-Shally Basin	Ethiopia	The purpose of the project is to ensure a balanced Ziway-Shalla Basin ecosystem with a sustainable and transparent water usage and distribution system and to improve water security and income of small (female) farmers in the lake Ziway area. Besides introduction of drip irrigation also attention is paid to improved furrow irrigation to achieve a higher irrigation efficiency.
11	FDW (17253ET)	Water Pricing for Sustainable and Inclusive Growth	Ethiopia	The aim of the project is to improve the water resources management for more equitable and efficient water use in Awash sub-basin. This done through installing water measuring equipment and implementing a water allocation plan and a water charging system. Drip irrigation is just one of the measures to reduce water consumption and is promoted through pilots and farmer-to-farmer exchange visits.
12	FDW (17109IN)	Water Efficiency in Sustainable Cotton-based Production Systems in Maharashtra, India	India	The goal of this project is to contribute to an increase in water availability, water efficiency and reduced water stress for the cotton farmers. Contribute to sustainable livelihood of farmers by facilitating the adoption of sustainable production practices and increase yield and cotton quality. Drip irrigation is seen as a method to improve yield and increase water efficiency in water scarce scenarios by climate change. Drip irrigation is promoted through demonstration plots and trainings through participatory group discussions.
13	SDGP (1017TZ)	Eat Fresh	Tanzania	The aim is the improvement of the performance of the horticultural sector in the Southern Highlands. Agriculture is currently mainly rainfed. Continuous availability and application of water is considered key in the development of the horticultural sector in which drip irrigation will play a role. Drip irrigation is promoted through demonstration and training
14	SDGP (1085NG)	Transforming Nigeria’s Vegetable Markets	Nigeria	The project endeavors productivity increase of the domestic vegetable sector by bringing knowledge and introducing new varieties and adapted technologies. The project has a focus on agronomical measures and sees a future role for drip irrigation. Currently drip irrigation is demonstrated on a limited scale in ‘ Learning Sites’.

Annex 2 Indicators of good agricultural water use

The promotion of drip irrigation and the high expectations that are widely put on it are strongly linked to its image as 'water saving technology'. Often where drip irrigation is mentioned or promoted is in the first place an expression of a desire to improving water use.

In this annex we define words that are commonly used to characterize "good agricultural water use practices" and we explain their differences. We also discuss frequently used indicators to monitor water impacts and do this in relation to project and policy objectives. These indicators each have different methodologies for capturing data, with some important implications. We discuss *water productivity* and *irrigation efficiency* as two commonly used terms and relate them to how improvements in *productivity* and *efficiency* may affect water availability for other users.

Water productivity

In the debates around good agricultural water use, *water productivity* has become an increasingly important concept, both in scientific debates and in policy circles. In its most simple definition water productivity is about the amount of crop production per amount water used. It is usually expressed in kilogram per cubic meter of water (kg/m^3). As a policy concept *water productivity* steers people to think about how production can be increased without increasing the amount of water used. A high water productivity is considered to be good. In praxis and in policy circles water productivity is often not much more defined than in these broad terms. In science there are however requirements to define the concept much more narrowly in order to be able to measure and compare water productivity. These refinements also have policy-relevant consequences, many of which are often overlooked.

Water productivity: crop production per amount water used

Box 2 – Water productivity in science

The concept of water productivity (WP) is a key term in evaluation of agricultural water use and defined as the value or benefit obtained from the use of water (Molden et al., 2010). WP is based on "more crop per drop" .

$WP = \frac{Y}{ET}$ (kg/m^3)

This equation indicates the ratio of agricultural output to the amount of water consumed. Agricultural output can be expressed in Biomass (BM) or Yield (Y), in both cases unit kg's. The amount of water used is the Evapotranspiration (ET) in cubic metres (m^3), the sum of the Evaporation (E) of the soil and Transpiration (T) of the crop.

1. Crop production is often expressed in *total biomass* and thus includes those parts of the plant that are not considered useful production. In this case a maize field with a lot of cobs compares equal to a maize field that has produced a lot of leaves, but hardly any cobs.
2. Alternatively, crop production can also be expressed as *yield*, the beneficial harvest. However, as the weight of for instance potatoes can be hardly compared to the weight of wheat grains, a comparison between crops is not possible.
3. In science the 'water used' is defined as the *evapotranspiration*, the water evaporated from the soil plus the amount transpired by the plant. Calculating water productivity on basis of transpiration implies that it focusses on how efficient plants use water in their organisms to

produce biomass. Transpiration is thus a very specific delimitation with very specific consequences for what is and what is not made visible.

In day-to-day policy and praxis 'water used' is often understood much more broadly, for instance as water applied to the field, or even as water abstracted from a source. In scientific debates these calculations would however not be referred to as water productivity. To avoid further confusion, when we refer to a calculation of 'production per transpiration', in science simply referred to as *water productivity*, in the remainder of this document we use the term '*biophysical water productivity'*.

To better explain the implication of the *biophysical water productivity* indicator, we discuss examples to illustrate what is not made visible.

- From rainfed production to irrigated production. When farmers introduce irrigation on their field often this goes along with a change in crops. Yield of rain-fed maize is incomparable to yield of irrigated vegetables. When the crop remains the same, such as can be the case in sugar cane farming, the yield can be expected to increase, but in most cases this will increase with a factor (almost) the same as the increase in *evapotranspiration*. If yield increases 1.5 times also *evapotranspiration* increase by a factor 1.5 and *biophysical water productivity* will remain roughly the same.
- From deficit irrigation to over-irrigation. When farmers supply more water to their crops than what is needed the additional water either drains as groundwater or flows off over the surface, for instance into a (natural) drain. These can be substantial volumes, but this does not directly affect the *evapotranspiration* and yield. Over-supply of water does therefore not become directly visible in *biophysical water productivity*. Only when fields become so wet that it hampers plant growth *biophysical water productivity* may go down.
- From surface irrigation to drip irrigation. A change from applying water directly to the soil surface through furrows or basins to more localised application by for instance drip emitters can lead to less wetted soil surface and less over-irrigation. However, under drip irrigation the part of the soil that is wetted often remains permanently wet, whereas under other water application methods the soil is only wetted intermittently. Drip irrigation therefore does not always have a lower evapotranspiration than surface irrigation. Moreover, deep percolation of water due to over-irrigation does not affect *biophysical water productivity*.
- Good agricultural practices. When plants are well taken care off, such as through good nutrient and pest management, optimal plant spacing and timely application of water, they grow more healthy and are more efficient in producing biomass and beneficial yield. True gains in water productivity are those where yield increases are achieved without increases in evapotranspiration, or where evaporation from the soil is reduced through practices as mulching and localized irrigation while maintaining or increasing production (Halsema & Vincent, 2012).
- Increasing the cropped area. The area that farmers use does not affect *biophysical water productivity*. There are however several known cases where farmers actually increased their cropped area following introduction of drip irrigation. With the same amount of water abstracted a larger area can be grown. In some cases farmers even started abstracting more water (Garb & Friedlander, 2014; Sese-Minguez et al. 2017).

Biophysical water productivity thus indeed focusses on plant production efficiency and does not allow for monitoring other concerns in improving agricultural water management, such as water losses, distribution between users, economic use of water, and poverty impacts. In the next paragraph we discuss what the indicator *irrigation efficiency* might contribute to it.

Irrigation efficiency

In colloquial speech the expression 'efficient water use' has become very common as a practical substitute for good water use. In science, the concept of *irrigation efficiency* has been in use for decades to be able to compare the efficiency of different irrigation systems and methods to apply water to the field. In its most simple definition *irrigation efficiency* is about the percentage of the water that reaches its destiny.

Irrigation efficiency: the % of the water that reaches its destiny

The analysis of *irrigation efficiencies* can be done at any part of a system or any system as a whole. To understand the meaning and implications of a reported *irrigation efficiency* it is extremely important to be aware of which parts of the water system are included in the calculation. This is best explained using an example.

If 10 m^3 is pumped up and 8 m3 of this reaches the fields, the *efficiency* of the canal system is 80% (see figure 1 below). If of the 8 m3 that is put onto a field 4 m^3 ends up the rootzone of the soil, the *efficiency* of this water application is 50% (4 divided by 8). The overall *irrigation efficiency* from pump to root zone is 40% (4m^3 of the 10m^3 pumped up).

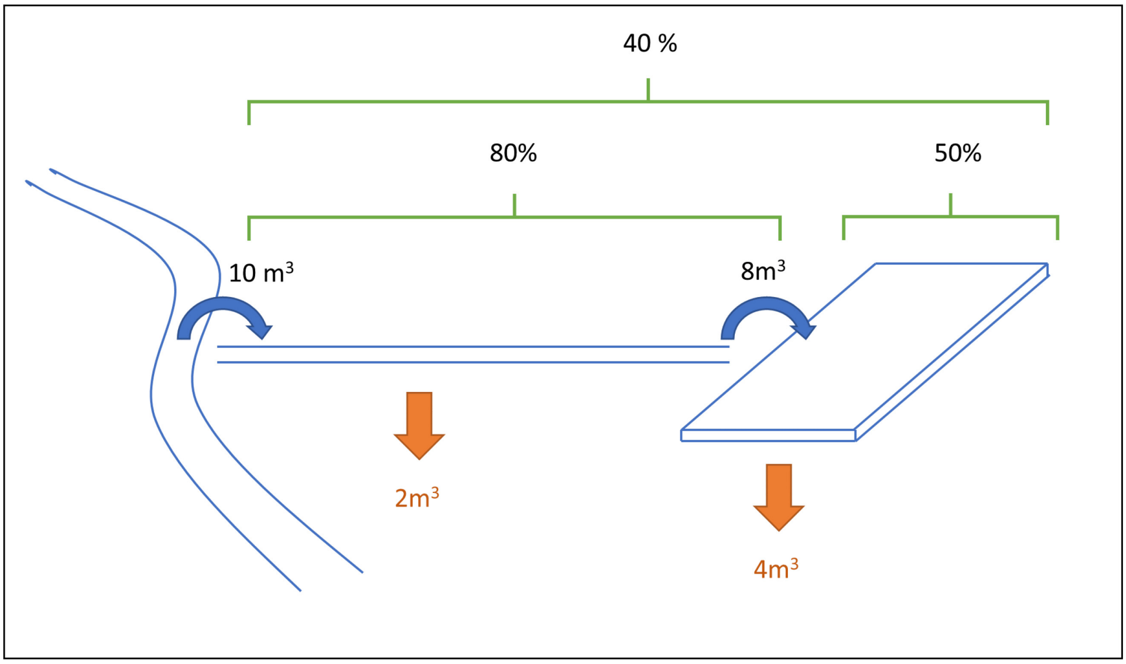

Figure 2 *Schematic representation of an irrigation system and calculation of efficiencies (explanation in the text immediately above)*

The water that does not reach its destiny is technically considered a loss (the red arrows in figure 1). The 2 m^3 that were lost from the canal and the 4 m^3 that did not end up in the root zone of the field may have flowed down to the next farmers field and may have been used there. Or part of it may have percolated so deep that the crop cannot reach it, but where it does contribute to ground water recharge. Both the next farmer and the users of the groundwater value the 'losses' as a resource. Improving *irrigation efficiencies* entails reducing 'losses'. Fixing leakages in the canal may reduce the losses from the canal, but this may actually imply that others lose it as a resource. It is therefore useful to make a distinction between losses that are recoverable for other use and non-recoverable losses (Lankford, 2006).

Box 3 – Irrigation efficiency in science

Irrigation Efficiency is a traditional concept that is used in irrigation engineering (Israelsen, 1950). It provides a measure of the overall functioning of irrigation inside a certain area. This does not look at any physiological plant or soil characteristic because harvest or product is not taken into account. In an equation it is expressed as follows.

Irrigation Efficiency = $\frac{water\ beneficially\ used}{total\ water\ applied}$ (%)

Therefore, irrigation practices that have a high *efficiency* are not per definition good for other users. Improving *irrigation efficiency* does not per definition increase water availability for others, because of losses that can be return flows but also because an higher efficiency does not imply less water abstraction. This is also referred to as "dry" and "wet" water savings, where the latter indicates a water saving that makes water available for other uses and the former a saving that is used at the place where the saving was made and thus does not become available elsewhere in the basin (Seckler, 1996).

Combining water productivity and irrigation efficiency?

In the praxis of policies and projects water productivity is often understood broader than *biophysical water productivity*. There is a broadening of the interest on production side of the equation (e.g. what crops are being produced, what is the nutritional or economic value of production, who produces it and who gets the benefits?) as well as on the water use side of the equation an interest in understanding (e.g. how much water is diverted, how much water is lost, how does this relate to other uses in the basin?). The *sec* biophysical understanding of *water productivity* is deemed too narrow to cover the relevant questions with regards to efficient use of water for agriculture. What is reported as water productivity is therefore in practice often a combination of *biophysical water productivity* and *irrigation efficiency*. The production is divided by an amount of water that is larger than just the evapotranspiration, e.g. the 'water applied to the field' or the 'water abstracted from the source' (respectively the 8 m^3 and 10 m^3 in figure 1).

In science this is referred to as *water use efficiency* and, just like *water productivity*, is expressed in kg/m^3. In the praxis of policies and projects it is sometimes referred to as *water use efficiency*, but more often simply as *water productivity*.

Going back to the example illustrated in figure 1, we assume that 10 kg yield comes from this plot. The *biophysical water productivity* would be about 2.5 kg/m^3, as the evapotranspiration in this case will be more or less equal to the $4m^3$ water in the rootzone leading to the calculation 10 kg divided by 4 m^3. Yet, in their interpretation of water productivity, many projects interpret 'water used' as the 'water applied to the field' or the 'water abstracted from the source'. These would respectively report a *water productivity* of 1.25 kg/m^3 and 1.0 kg/m^3 (10 kg divided by 8 m^3 and 10 kg divided by 10 m^3).

These numbers are heavily influenced by the losses in different parts of the irrigation system (the red arrows in figure 1). Reducing these losses in irrigation systems increases *water productivity* numbers calculated in this manner. That is: if *water productivity* is understood and calculated on basis of water flows such as 'water applied to the field' or the 'water abstracted from the source', it also steers to reducing losses at system level. Yet, as shown in the section above on irrigation efficiencies, these losses can be considered 'unimportant to reduce', for instance when they can be recovered downstream, or even 'undesirable to reduce', for instance when they already contribute to downstream uses. Depending on context these broader interpretations of *water productivity* can be relevant and useful, but it is important to be aware what numbers are being reported to be able to have meaningful discussions on basis of them.

Measuring

Besides implications of the way in which water productivity and irrigation efficiency are understood, there are also practical considerations in using these indicators.

Monitoring and evaluation of project interventions is an important part in project implementation. However, measuring WP and IE is difficult. Looking at the different components of WP and IE some elements can reasonably well be measured but important parameters are extremely difficult to determine. For WP the actual evapotranspiration of the crop and yield are key elements. Yields can be measured quite straightforward but actual evapotranspiration needs highly advanced research methods used in research settings. Remote sensing techniques are developed to measure it on a broader scale but accuracy levels are limited up till now.

For IE the amount of water applied and water reaching the rootzone ("beneficially used") play a crucial role. Monitoring the application of water can be done fairly straightforward. However, partitioning of the parts that end up in the rootzone, run-off or deep percolate is complicated and needs a well-structured research set up mostly not available at project level. Uncertainties in various elements of the equation result in a limited accuracy of the WP or IE indicator and limit the comparability between projects.

Annex 3 Useful Further Reading

Allen R.G. et al. (1998) Crop evapotranspiration - Guidelines for computing crop water requirements, FAO Irrigation and Drainage Paper 56, Rome. http://www.fao.org/3/x0490e/x0490e00.htm	A comprehensive method to calculate crop water requirements and irrigation scheduling on the basis of climate, crop and soil data
Boesveld, H.; Zisengwe, L.S.; Yakami, S. (2012) Drip Planner Chart: a simple irrigation scheduling tool for smallholder drip farmers. Irrigation and Drainage Systems 25 (4). - p. 323 – 333	A manual calculation tool for drip irrigation scheduling for smallholder farmers with a low cost drip irrigation system.
Brouwer C. et al. (1989) Irrigation Methods, FAO Training manual no 5, Chapter 7: Choosing and irrigation method. Rome http://www.fao.org/tempref/agl/AGLW/fwm/Manual5.pdf	This chapter gives guidance and indicates several important criteria in the selection of a suitable irrigation method like drip- sprinkler- or surface irrigation.
Halsema, G. E. Van, & Vincent, L. (2012). Efficiency and productivity terms for water management : A matter of contextual relativism versus general absolutism. Agricultural Water Management, 108, 9–15.	Definitions and background on concepts of Water Productivity (WP), Irrigation Efficiency (IE) and Water Use Efficiency (WUE)
Merrey, D. J.; Lefore, N. 2018. Improving the availability and effectiveness of rural and “Micro” finance for small-scale irrigation in Sub-Saharan Africa: a review of lessons learned. Colombo, Sri Lanka: International Water Management Institute (IWMI). 46p. (IWMI Working Paper 185). doi: 10.5337/2018.225	A practical Working Paper with a lot of examples of current experimentations with finance for small-scale irrigation in Africa
Phocaides A. (2007) Handbook on Pressurized Irrigation Techniques, Chapter 14: Drip Irrigation. FAO, Rome. http://www.fao.org/3/a1336e/a1336e.pdf	A practical handbook on advantages and disadvantages of drip irrigation, system layout, components, irrigation scheduling and design criteria for drip irrigation.
Phocaides A. (2007) Handbook on Pressurized Irrigation Techniques, Chapter 15: Low-cost family drip irrigation system. FAO, Rome. http://www.fao.org/3/a1336e/a1336e.pdf	Conventional drip irrigation is constrained by the high initial capital cost and the relatively sophisticated level of management. Simplified drip systems for small land ranges of 100 – 500 m² have been developed.
SNV Netherlands Development Organization. Smart Water Solutions for Enhanced Livelihoods and Profitable Agribusiness. Smart Water for Agriculture (SWA), Nairobi.	This practitioner guide presents the lessons learnt with regards to the strategies of promoting Simple, Market-based, Affordable, Replicable and Technically feasible (SMART) irrigation technologies, agronomic and water management practices in Kenya, including drip irrigation
SNV Netherlands Development Organization. Platforms for Brokering and Learning: Lessons on Multi-Stakeholder Collaboration for Farmer-Led Irrigation Development. Smart Water for Agriculture (SWA), Nairobi.	Irrigation Acceleration Platforms as multi-stakeholder arena’s for the assessment, development and promotion of existing and new irrigation solutions, taking into account the requirements of the farmers, as well as the business considerations of the solution providers.
SNV Netherlands Development Organization. Accelerating Farmer-led Irrigation Development: Theory and practice of the Smart Water for Agriculture in Kenya project. Smart Water for Agriculture (SWA), Nairobi.	In many parts of Africa small- and medium scale farmers are making substantial investments in irrigation development, which, when combined, cover thousands of hectares. In these cases, farmers have assumed a driving role in developing or improving their water use for agriculture. This is what is called farmer-led irrigation development (FLID).
Venot J.P., Kuper M., Zwarteveen M.Z. (2017) Drip Irrigation for Agriculture: Untold Stories of Efficiency, Innovation and Development. Routledge	This book documents the enthusiasm, spread and use of drip irrigation systems by smallholders but also disappointments and disillusion faced in the global South. It explores and explains under which conditions it works, for whom and with what effects.

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