

Master Thesis

**Optimization of a tool for the choice of an irrigation system
based on local parameters**

Master of Science

Ufuk Akay

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Supervisor: Prof. Dr.-Ing. Ralf Otterpohl

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1. Introduction

The population on the world is growing every second. For the growing population more water and food is needed, but fresh water is a rare resource and will become a much more scarce resource in the future on the earth. The private water as well as the industrial water consumption is increasing continuously. The water shortage on the earth affects the population now and will affect the population (especially in the developing Countries) more and more in the future. The lack of water also has effects on the hunger in the world. Without enough water, the food cannot be produced in a sufficient degree to feed the whole population.

According to the federal agency for civic education of Germany, improved and field fitting irrigation technology can help to reduce this problem.

A manual selection of a field fitting irrigation system is very complex and extremely time consuming. The irrigation system must be set by the local and individual field parameters for every field, because the local soil-, water- and climate parameters are different on every field. Desertification and degradation of the soil can occur if the irrigation system is not adapted to the field.

In this thesis the existing tool of the bachelor thesis (*Development of a tool for recommendation of irrigation systems based on local parameters, 2013*) will be optimized so that a better recommendation for a field fitting irrigation system can be given. Through the better recommendation the risk of desertification and degradation of the soil can be reduced and the productivity of the farming can be increased.

The content of chapter 3 of this thesis is copied from the bachelor thesis and included after translation in English, to have a better knowledge of the discussed topics of the bachelor thesis and to show the development of the existing tool.

2. ecological, social and agricultural problems

There are several ecological, social and agricultural problems. These problems are discussed in the following chapters.

2.1 ecological problems

According to the federal agency for civic education of Germany there is around 0,008% of the total amount of the water in the world that can be directly used for irrigation, as seen on Figure 1.

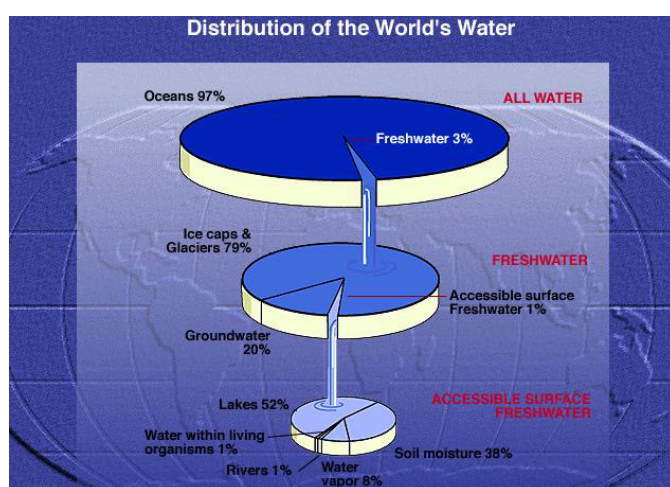


Figure 1 water distribution of the world (water distribution, 2015)

The global water consumption has increased approximately six-fold from 1930 to 2000 and will increase more in the future. In the best-case the water shortage in the middle of this century will affect 48 countries and 2 billion people. In the worst-case 60 countries and 7 billion people will be affected by it. According to the federal agency for civic education of Germany improved irrigation technology and cultivation of adapted products in the agricultural sector can help to reduce this problem. (bpb.de water, 2015)

2.2 social problems

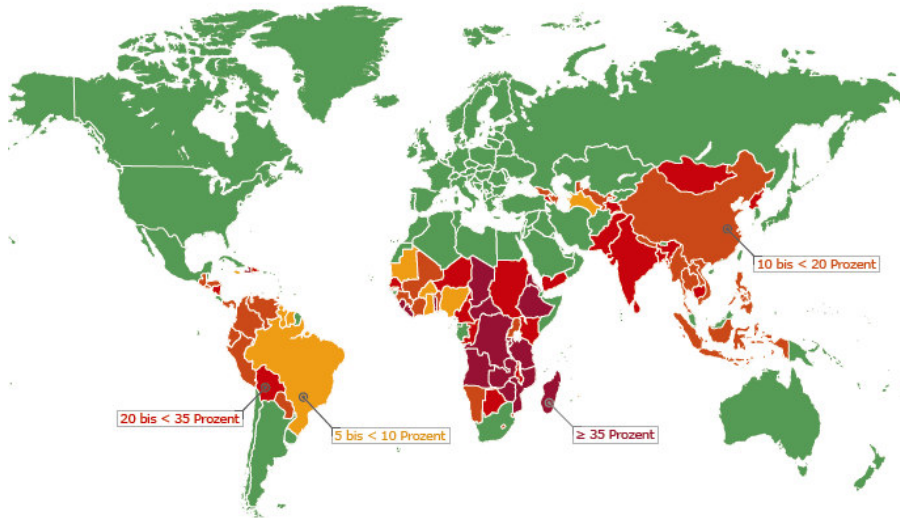
According to the federal ministry of economic cooperation and development of Germany 250 people die every 15 Minutes because of hunger.

2. ecological, social and agricultural problems

As you can see on Figure 2 the areas with the high malnutrition are poor countries and not good developed countries.

■ Unterernährung

Anteil der unterernährten Bevölkerung in Prozent, nach ausgewählten Staaten, Betrachtungszeitraum 2004 bis 2006



Quelle: Food and Agriculture Organization of the United Nations (FAO): The State of Food Insecurity in the World 2009
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Bundeszentrale für politische Bildung, 2010, www.bpb.de

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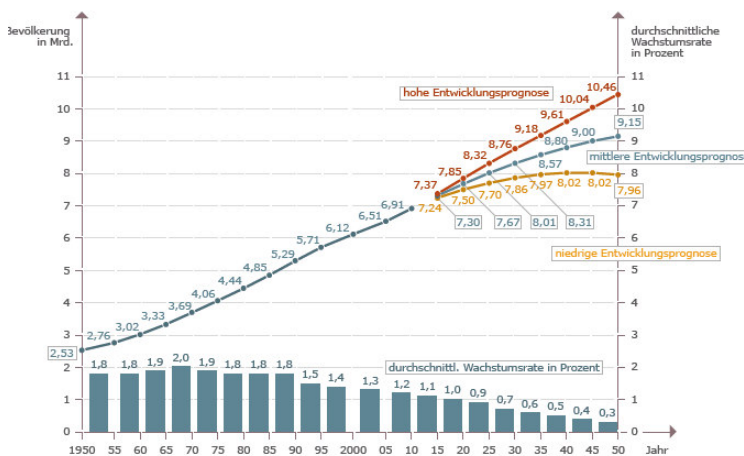
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Figure 2 malnutrition (bpb.de malnutrition, 2015)

As you can see on Figure 3 today there are 7,2 billion people in the world, against the population in 1950 it is a tripling. The forecast of the UN / DESA for the population in the year 2050 is a range from 8.0 to 10.5 billion. With the population-increasing the water consumption and the food demand will also do so. (bpb.de population, 2015)

■ Bevölkerungsentwicklung

Bevölkerung in absoluten Zahlen und Wachstumsrate pro Jahr in Prozent, weltweit 1950 bis 2050



Quelle: UN/DESA: World Population Prospects: The 2008 Revision (Stand: Mai 2010)
Lizenz: Creative Commons by-nc-nd/3.0/de
Bundeszentrale für politische Bildung, 2010, www.bpb.de

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Seite 27

Figure 3 population in the world (bpb.de population, 2015)

2.3 agricultural problems

It is not possible to develop one irrigation system and build the same irrigation system all over the world, the local soil-, water- and climate parameters are different everywhere. The irrigation system must be set by the local and individual field parameters for every field. But the manual selection of an irrigation system is complex and time-consuming.

If the irrigation system is not set by the local and individual field parameters in an extreme case desertification and degradation of the soil can happen, so that the soil is damaged for a long time. (Achtnich, 1980)

3. structures of irrigation systems

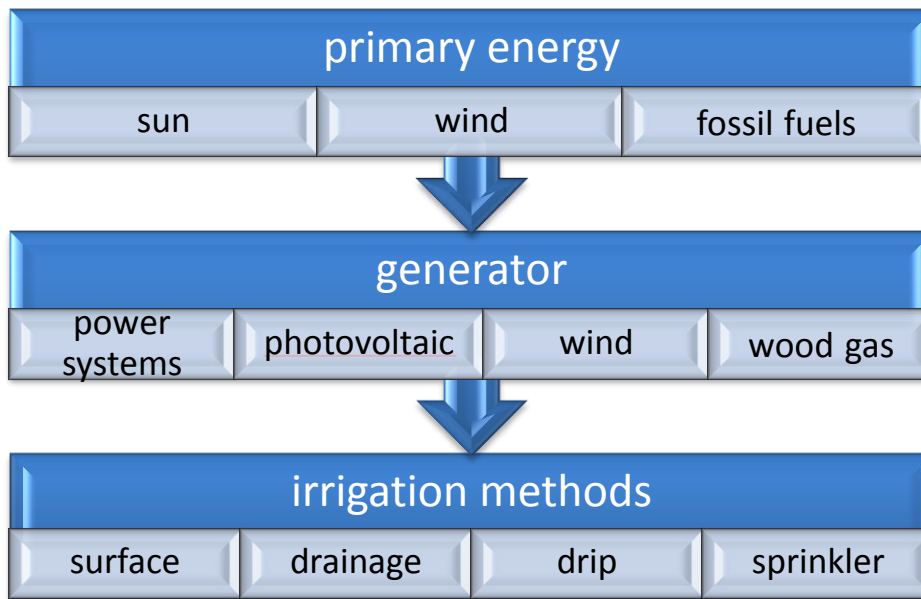


Figure 4 structure of irrigation systems

Figure 4 shows the simple structure of irrigation systems.

The primary energy is divided by natural energy (i.e. sun, wind) and fossil fuels (i.e. diesel, gas). This primary energy has to power the generator of the irrigation system. The generator will generate electricity from this primary energy. The electricity from the generator is needed to power the pump. The pump will bring water from the water source to the field with the needed pressure. The water can be distributed on the field by the chosen irrigation method.

3.1 water source

There are different sources to get the water for the irrigation system:

- surface water
Standing water and flowing waters are possible sources for withdrawals for irrigations.
- precipitationwater
It is possible to save the precipitation in tanks in the humid and rainy months. In the months without precipitation the water from the

3. structures of irrigation systems

tank can be used for the irrigation. These tanks need to be big to ensure the irrigation in long-lasting dry periods. If the water in these tanks are totally consumed a new water source needs to be found. (hausgarten, 2015)

- groundwater
The precipitation which ooze away through the soil to the aquifer can be withdrawal with wells to be used or irrigation. (Pfleger, 2009)
- cleaned wastewater
Wastewater can be cleaned so that it can be used for irrigation. (Neubert, 2003)

3.2 pump

To pump the water from the water source to the field a pump is needed. To ascertain which pump is needed for the irrigation two parameters needs to be known. The conveying capacity and the static head. (Johannsen, 2011)

Steps to solve the problem:

1. Height difference from the highest fieldpoint to the water surface
2. Solve the static head with the Bernoulli equation:

$$\frac{va^2}{2 * g} + \frac{pa}{\rho * g} + za = \frac{ve^2}{2 * g} + \frac{pe}{\rho * g} + ze$$

With the variables:

g gravity

ρ density of the fluid

va flow rate of the beginning point

pa pressure of the beginning point

za height of the beginning point

ve flow rate of the end point

pe pressure of the end point

3. The water demand of the plants on the field is needed, to calculate the conveying capacity. The water demand for each plant is different. I.e. for wheat 3mm precipitation is needed per day and for potatoes 1mm. The water demand has to be multiplied with the field ar-

3. structures of irrigation systems

ea to calculate the conveying capacity and to ascertain the pump.
(Siegert, 1927)

3.3 Irrigation methods

Surface irrigation, sprinkler irrigation, drip irrigation and drainage irrigation can be used as irrigation methods. In the following chapters they will be explained and the advantages and the disadvantages will be shown.
(Achtnich, 1980)

3.3.1 surface irrigation

The surface irrigation can be divided in basin irrigation, strip irrigation and furrow irrigation. (Achtnich, 1980)

3.3.1.1 basin irrigation

For irrigation with basins the field must be divided in zones like, see Figure 5.



Figure 5 basin irrigation (Achtnich, 1980)

The water is precluded from the ditches and the water ooze away in the soil. The basin irrigation do not fit for all plants.

The ooze away of the water can lead to eluviation. The standing water leads to that no erosion and soil salinization can happen. (Achtnich, 1980)

The sizes of the basins are variable and the size can be, depending on the location and plants, between a few square meters to several hectares. The boundaries of the basins are formed by piled up soil. They are between 15

3. structures of irrigation systems

cm to 45 cm high. Only the soil and few materials are needed to build basin irrigation, no machines are needed. From the water surface to the bottom tip of the boundaries 10 cm to 20 cm height difference is needed. The width of the boundaries for seasonal basins is between 60cm and 120 cm and for permanent basins up to 180 cm. To protect the boundaries membranes or films can be used. For the water distribution of the basin a constant low slope of approximately 0.1% is required. Stronger gradients and a strong slope of greater than 0.3% impair the efficiency of the system. For the basin irrigation a terrain with low ground slope and a soil with low infiltration degree is an advantage. In Table 1 the advantages and disadvantages of a basin irrigation are shown. (Achtnich, 1980),

Table 1 advantages and disadvantages of basin irrigation (according to Achtnich, 1980)

advantages	disadvantages
<ul style="list-style-type: none">• irrigation with big amount of water• no machines needed• less material requirements• no energy needs• no soil erosion possible• soil salinity almost not possible• low technical knowledge needed	<ul style="list-style-type: none">• no irrigation with small amount of water• high risk of leaching• hand work required• this irrigation method does not suit all kind of plants

3.3.1.2 strip irrigation

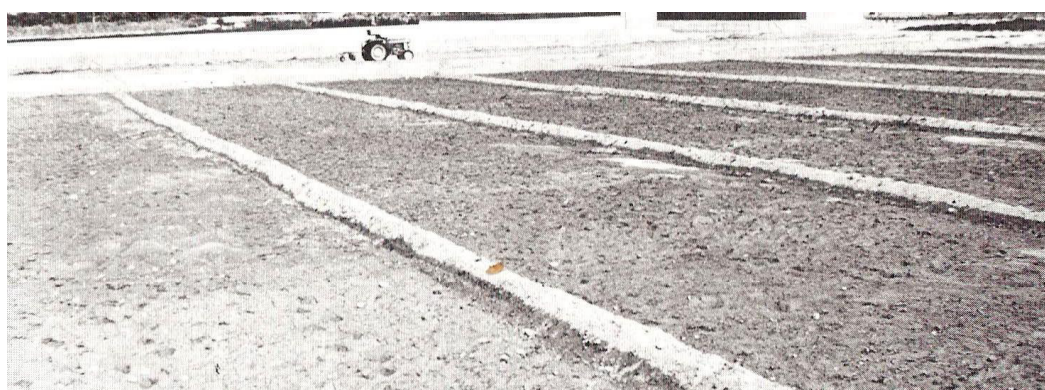


Figure 6 strip irrigation (Achtnich, 1980)

For a strip irrigation, shown in the Figure 6, the water flows over the field, so irrigation with small water amount is not possible. The flowed irrigation does not suit all kind of plants. The boundaries of the strips are formed by

3. structures of irrigation systems

piled soil. In addition to the soil few other materials are needed, so this process does not need much maintenance either. The slope of the land must be at least 0.2%. With higher permeability, the slope can be up to 2%. The maximum length of the strip of land can be 400 m and more, this distinction is made on the permeability of the soil. To minimize soil erosion, the usual widths of the strips of land are 10 m to 20 m. The water supply must be regulated. The water supply should be adjusted so that after three quarters of the strip of land get overflowed. The residual water, which is still on arable land after irrigation, should be removed in order to avoid salt deposits. Therefore, the use of saline water is detrimental. The strip irrigation is suitable for moderate and medium soil permeability. In Table 2 the advantages and disadvantages of a strip irrigation are shown. (Achnich, 1980)

Table 2 advantages and disadvantages of strip irrigation (according to Achnich, 1980)

advantages	disadvantages
<ul style="list-style-type: none">• irrigation with big amount of water• small material requirements• low technical knowledge needed• low energy needs• low maintenance	<ul style="list-style-type: none">• no irrigation with small amount of water• does not suit to flat fields• not useable with salty water• this irrigation method does not suit all kind of plants

3.3.1.3 furrow irrigation



Figure 7 furrow irrigation (Satego, 2015)

3. structures of irrigation systems

As shown in Figure 7 furrows are shaped as small trenches. The grooves have a V, round- or shallow grave form. The furrows are usually 20 to 40 cm wide and 15 to 25 cm deep. The distance between the grooves is 50 to 150 cm. The water infiltrates sideways through the furrow in the ground and goes into the plant root. The irrigation is only possible with large amounts of water because the grooves must be filled with water. A wash-out is possible with furrow irrigation. If saline water is used for irrigation, it can lead to salinization of the tops. Only a little amount of material is required. Small technical understanding is required for the furrow irrigation. A minimum slope of 0.5% is needed for the furrow irrigation and therefore the irrigation method is not suitable for flat terrain. If the minimum slope is available on the field almost no energy is needed for the irrigation. The advantage is a uniform flat slope. Different slopes are possible, depending on the soil cohesiveness. The furrows length depends on the soil type. On light soils the furrow length should be limited to a maximum of 100 m and in cohesive soils up to 200 m. The advantages and disadvantages of furrow irrigation are shown in Table 3. (Achtnich, 1980)

Table 3 advantages and disadvantages of furrow irrigation (according to Achtnich, 1980)

advantages	disadvantages
<ul style="list-style-type: none">• low material requirements• low maintenance• low technical knowledge needed• low energy needs	<ul style="list-style-type: none">• no irrigation with small amount of water• risk of leaching• not suit to flat fields• not useable with salty water• this irrigation method does not suit all kind of plants

3.3.2 sprinkler irrigation

The irrigation of the plants with the sprinkler irrigation is done by a regulated rain-like irrigation. This irrigation method is not suitable for all plants. The sprinkler irrigation is divided between moving irrigation (see Figure 8), stationary (see Figure 9) and in part fixed installations. (Achtnich, 1980)

3. structures of irrigation systems



Figure 8 moving sprinkler irrigation (klett, 2015)

Mobile sprinkler irrigation, are mounted on a mobile frame and the frame is driving with the sprinklers to irrigate the fields. Uneven terrain is difficult for movable irrigation systems, the tires of the movable irrigation system cannot move on the uneven terrain.



Figure 9 stationary sprinkler irrigation (mnrainman, 2015)

Strong winds and high temperatures make the use of sprinkler irrigation difficult as an irrigation method. The irrigation should be in the evening or morning hours to avoid high evaporation. The irrigation systems are adjustable so that the amount of water, drop size and density of rain are variable. If the sprinkler irrigation is used as irrigation method, both small and large amount of water can be irrigated. By irrigation, the soil fertilizers can be supplied, so that a multi-purpose of the irrigation method is possible. Very suitable soils for this type of irrigation are sand, loamy sand and sandy loam, so that the water is quickly absorbed into the ground. The water should be free of suspended solids and salt, which could clog the system. The irrigation systems can be automatically controlled by a control panel. High investment costs are required. Technically qualified personnel

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should be available for repair and service. The workshop should be close, so that defect parts can be fixed as soon as possible. One disadvantage with circle sprinkler irrigation systems is that the fields usually are rectangular, and so the corners cannot be well watered by the circle irrigation. (see Figure 10). (Achtnich, 1980)



Figure 10 circle sprinkler irrigation (Sonnentaler, 2015)

In Table 4 advantages and disadvantages of sprinkler irrigation are shown.

Table 4 advantages and disadvantages of sprinkler irrigation (according to Achtnich, 1980)

advantages	disadvantages
<ul style="list-style-type: none">• no soil erosion possible• controllability of rain amount• automation of irrigation possible• suitable for light soils• suitable for narrow field• multi-purpose use for fertilizer possible	<ul style="list-style-type: none">• disability by wind• high operating costs• high investment costs• not suitable for use of saline water• this irrigation method does not suit all kind of plants• power requirements• technical knowledge required• lot of equipment needed

3.3.3 drip irrigation

The drip irrigation system is characterized by the distribution of water at low water pressure with so-called droppers. With the droppers, the soil is moistened in the radiation area of the dropper (see Figure 12). Not all plants are suitable for this type of irrigation. A schematic of the drip irrigation system is shown in Figure 11. The water comes from the hydrant line and passes the electrical control unit (energy consumption) in the mani-

3. structures of irrigation systems

fold. From there, the water is distributed into the drip lines. In these drip lines the droppers are built in, to irrigate the fields in the distribution area. By this technically complex structure of the drip irrigation technical knowledge is required. (Achnich, 1980)

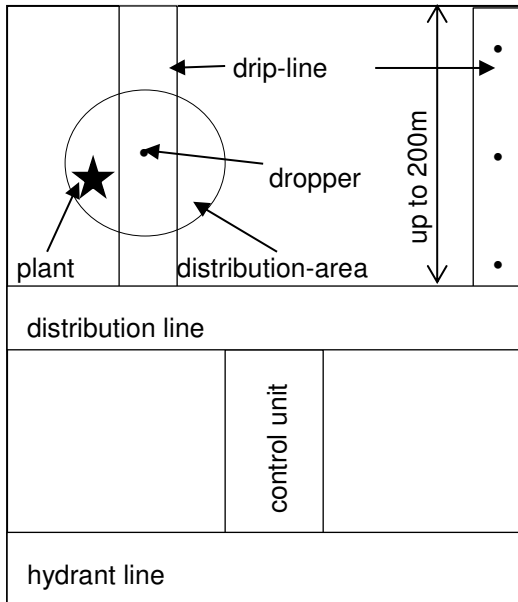


Figure 11 schematic of a drip irrigation (according to Achnich, 1980)

The soil for the drip irrigation can be both light and heavy. The drip irrigation can be used for any slope. By irrigation with sprinklers neither a washout nor an erosion of the soil is possible. With a drip irrigation both small and large amounts of water can be irrigated. With the controllable amount of water, the distribution area and humidification can be regulated. With the small radiation area of the dropper water losses are low due to evaporation. The dropper can be built in either as nozzles or orifices in the drip line. These openings are indeed cheaper, but do not allow precise water distribution. The drip irrigation can also be used for fertilizer and pesticides, so that multi-purpose uses are possible. The use of saline water can cause salt deposits in the distribution area of the dropper so that a flushing of the salt must be carried out by flood irrigation of the land. A blockage of the dropper can also happen. The advantages and disadvantages of drip irrigation are shown in Table 5. (Achnich, 1980)

3. structures of irrigation systems



Figure 12 dropper (Krühler, 2007)

Table 5 advantages and disadvantages of drip irrigation (according to Achtnich, 1980)

advantages	disadvantages
<ul style="list-style-type: none">• multi-purpose use for fertilizer possible• automation of irrigation possible• low water losses• controllability of water amount• good water distribution• automation possible• for each slope possible• no soil erosion possible• suitable for light and heavy soils• no possibility of leaching	<ul style="list-style-type: none">• high operating costs• high investment costs• this irrigation method does not suit all kind of plants• power requirements• high material requirements• lot equipment needed• technical knowledge required

3.3.4 drainage irrigation

In the drainage irrigation water is supplied to the plants under the field surface. Not all plants are suitable for this type of irrigation. This irrigation works with pipes in the ground. There are a number of variations of drainage irrigation.

Drainage pipes can be used for the irrigation. The drainage can be used as needed as a drainage system or as an irrigation system. One drainage pipe which open in the feeders should be built every 300 m, other pipes should be at least at a distance of 25 m and flow into a drainage pipe at the beginning and at the end of the pipe. A uniform water distribution is possible. The water distribution can be controlled. With a lot of material high system costs and operating costs comes along. With the drainage irrigation small and large amount of water can be irrigated. Fertilizers can also be supplied, so that a multi-purpose use is possible. The water should

3. structures of irrigation systems

be neither defiled nor salty, to prevent clogging of the pipes. With underground water transfer irrigation lines no place on the surface is needed. As a result of the underground water transfer losses due to evaporation is low, so neither a washout nor an erosion of the soil is possible. There are also other types of irrigation through drainage pipes that is not discussed here. (Achtnich 1980)

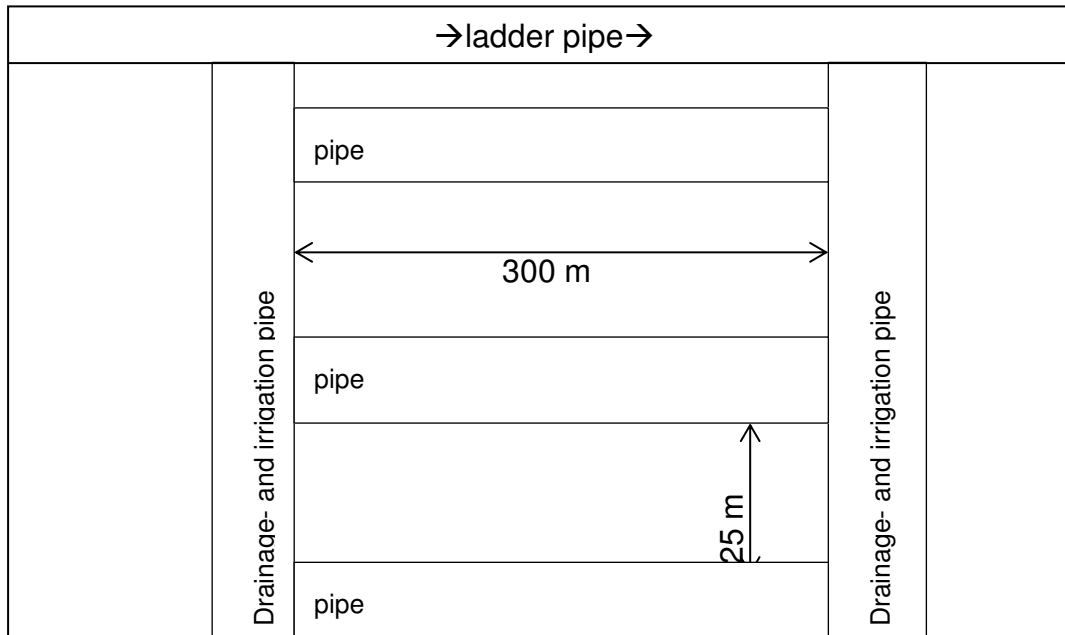


Figure 13 scheme of an drainage irrigation (according to Achtnich, 1980)

In Table 6, the advantages and disadvantages of drainage irrigation are shown. (Achtnich 1980)

Table 6 advantages and disadvantages of drainage irrigation (according to Achtnich, 1980)

advantages	disadvantages
<ul style="list-style-type: none"> • multi-purpose use for fertilizer possible • no loss of field surface • controllability of water amount • good water distribution • no soil erosion possible • no possibility of leaching 	<ul style="list-style-type: none"> • high operating costs • high investment costs • this irrigation method does not suit all kind of plants • not suitable for use of saline water • high material requirements • clogging risk • lot of equipment needed • technical knowledge required

3.4 generators

It is necessary to generate electricity for the water pump. The principles of different kinds of generators like a power station unit, a photovoltaic generator and a wind generator will be shown below, and their advantages and disadvantages are mentioned.

3.4.1 power station unit

Power generators transform mechanical energy into electrical energy. The main components are an internal combustion engine and a generator. The mechanical energy is generated by an internal combustion engine.

The generated energy from the mechanical engine is converted by the generator into electrical energy. In Table 7, Table 8 and Table 9 the advantages and disadvantages of gasoline, diesel and LPG generators is presented. (Lange, 2015)

Table 7 advantages and disadvantages of a gasoline generator (endress, 2015)

advantages	disadvantages
<ul style="list-style-type: none">• cheap to buy• lightweight, small and mobile• energy production is not depending on natural energy	<ul style="list-style-type: none">• expenses for fuel for the operation of the generator• fossil energy will not be permanently available• emissions of greenhouse gases (CO₂, methane)

The gasoline generator is cheap to buy and is in the current production not dependent on external energy such as sunlight or wind speed. In the operation of the generator gas and oil is needed. Gasoline is not a renewable resource, and has an emission of greenhouse gases.

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Table 8 advantages and disadvantages of a diesel generator (endress, 2015)

advantages	disadvantages
<ul style="list-style-type: none">• fuel cheaper than gas• energy production is not depending natural energy	<ul style="list-style-type: none">• expenses for fuel for the operation of the generator• fossil energy will not be permanently available• emissions of greenhouse gases (CO₂, methane)• large, heavy• expensive to buy

Raw material cost of the diesel generator is cheaper but has a higher purchase price than the gasoline generator. Another disadvantage is that the diesel generator due to the size and weight is not as mobile as the gasoline generator.

Table 9 advantages and disadvantages of a LPG generator (endress, 2015)

advantages	disadvantages
<ul style="list-style-type: none">• low cost of raw materials• energy production is not depending natural energy	<ul style="list-style-type: none">• fossil energy will not be permanently available• emissions of greenhouse gases (CO₂, methane)

The gas generator has, compared to diesel and gasoline generator, the lowest raw material costs.

3.4.2 photovoltaic generator

The photovoltaic generator generates electric power from solar radiation. A photovoltaic system should be set up so that solar radiation is not shaded. The inclination of the system should be aligned with 28° horizontal and facing to the south. The horizontal tilt can be either by a sloping frame on which the photovoltaic system is mounted to or the photovoltaic system is mounted on a roof with a horizontal tilt. Photovoltaic systems can be fixed or variable. In a fixed system the orientation angle of the system is constant and in a variable system, the system tracks the sun. The photovoltaic

3. structures of irrigation systems

system can be designed as a so-called stand-alone system or be connected to the mains. In grid systems, the current energy is not fed into the power grid, but used directly to run a pump. The advantage of grid systems is that the plant will be built from the power grid, so no power supply is needed. A battery can be installed as an energy storage as a buffer for times when no sunlight is available. In Table 10 the advantages and disadvantages of a photovoltaic generator are shown. (photovoltaic, 2012)

Table 10 advantages and disadvantages of a photovoltaic generator (endress, 2015)

advantages	disadvantages
<ul style="list-style-type: none">• primary energy available for free• no cost for raw materials• no emissions of greenhouse gases (CO₂, methane)	<ul style="list-style-type: none">• energy production depends on the clouds• energy production during the night not available• expensive

3.4.3 wind generator

A wind turbine is a generator for producing electrical energy from the use of wind energy. The main components of a wind turbine are the rotor, the tower and a generator. The wind goes to the blades, so that the rotor can generate mechanical energy. The generator transforms the mechanical energy of the rotor into electrical energy. (wind energy a, 2015)

The rotor of the wind turbine is made out of several blades. Wind turbines produce energy starting from a wind speed of 4m / s. At a wind speed of 25 m / s the wind generator is shut down so that no damage is made to the equipment. (wind energy b, 2015)

The wind turbines in an irrigation system are designed as so-called stand-alone system.. A battery can be installed as buffer for windless periods. (small wind turbines, 2015)

Wind pumps can also be used for irrigation, also called as western-mills. In this case an additional pump must be provided to establish the required pressure, which is necessary for irrigation. In Table 11 the advantages and

3. structures of irrigation systems

disadvantages of a wind generator are presented.

Table 11 advantages and disadvantages of a wind generator (endress, 2015)

advantages	disadvantages
<ul style="list-style-type: none">• primary energy available for free• no cost for raw materials• no emissions of greenhouse gases (CO₂, methane)	<ul style="list-style-type: none">• no energy production during wind speeds of 4 m / s or below• expensive• not good predictable energy

4. explaining the existing tool

To hold the thesis as short as possible this chapter is just an overview, for detailed information about the existing tool the bachelor thesis can be downloaded on the website of the Institute of Wastewater Management and Water Protection of the Hamburg University of Technology.

The tool is divided in 3 different sheets:

- recommendation of the irrigation method
- recommendation of the generator
- suitable plants and overview

4.1 recommendation of the irrigation method

This sheet first needs a user input with the given field parameters, water parameters, energy availability and the financial availability. The needed input of the field parameters can be seen below:

- soil slope
- risk of erosion of the soil
- salinization of the soil
- risk of water losses
- possibility of leaching
- energy resources
- initial budget
- annual Budget

For a recommendation of an irrigation method, recommendation matrixes for each of the parameters shown above are programmed in the tool. The tool is comparing the entered parameters from the user input with the needed parameters from the programmed recommendation, so that the tool can give a recommendation for the irrigation system that fits best to the field.

4. explaining the existing tool

The tool can recommend one of the following irrigation methods:

- basin irrigation
- furrow irrigation
- strip irrigation
- drainage irrigation
- drip irrigation
- sprinkler irrigation

4.2 recommendation of the generator

In the sheet cost comparison of the tool, the costs of different generator systems are calculated with economic methods and are compared so that the cheapest generator can be recommended.

The costs are calculated by year and presented in a diagram. The aim of this sheet is to find the cheapest generator for the irrigation system.

Data that needs to be entered from the user is:

- currency
- design time of the system
- investment cost of the pump
- investment costs of irrigation method

Data that needs to be entered from the user for each generator type:

- investment cost of the generator
- labor costs per year
- fuel costs per year
- replacement costs per year
- service and repair costs per year
- repayment term in years
- interest rate per year

4.3 suitable plants and overview

In the last sheet the user can see how suitable which plant is for the recommended irrigation system to cultivation.

The following plants are shown:

- grain
- rice
- sugarcane
- cotton
- root crops
- vegetables
- fodder plants
- green forest
- cotton crops
- crops

At last the user gets a graphical overview of all the tools recommendations (irrigation method, generator and suitable plants).

5. optimization of the tool

The most important optimization of the tool will be the enlargement of the field parameters to get a more detailed and better recommendation for an irrigation system. So an enhancement of the field parameters is needed.

Therefore the additional field parameters for the optimized tool will be:

- existing of loamy sand
- existing of clayey loam
- irrigation with big amount of water
- irrigation with small amount of water
- existing technical understanding
- possibility of automation
- use of machinery
- ground lost acceptable
- possibility of dosing the water
- even water distribution
- usage of saline water for irrigation

Every input which is needed from the user will be programmed as a drop down menu to make the input easier. Also there will be macros programmed for printing out every sheet and for resetting the input table.

Programming of the recommendation matrixes for the new field parameters

The programming and the development of the basic tool for the following parameters can be seen in the bachelor thesis:

- soil slope
- risk of erosion of the soil
- salinization of the soil
- risk of water losses
- possibility of leaching

5. optimization of the tool

- energy resources
- initial budget
- annual budget

The development of the recommendations and the programming of the new field parameters based on Table 12, are shown on the following pages.

5. optimization of the tool

Table 12 recommendation table (Achnich, 1980)

Zum Vergleich	Bewässerungsverfahren					
	Becken	Streifen	Furchen	Unterflur) ¹	Tropf-Bew.	Bereg-nung
Boden						
ebenes Gelände	5	0	0	5	5	5
mäßige Hanglage	3-4	4-5	5	3-4	5	5
steile Hanglage	2-4) ²	2-4) ²	2-4) ²	0	4-5	3-4
lehmgiger Sand (leicht)	3-5	2-4	2-4	3-5	5	5
toniger Lehm (schwer)	5	3-5	3-5	3-5	5	3-5
Erosionsgefahr	0	1-3	2-4	0	0	0-2
Versalzungsgefahr	1-2	1-3	3-5	2-4	1-3	1-2
Wasser						
kleine Gaben	0	0	0	2-4	5	5
große Gaben	5	4	3	2-4	2-4	5
verfahrenbedingter Bedarf	2-4	3-5	3-5	1	0	0
Dosierung	3	3	3	5	5	5
Wassererteilung	2-4	2-4	3-5	5	5	3-5
Wasserverluste	1-2	2-4	2-4	0	0	1-2
Gebrauch salzhaltigen Wassers	2-4	1-2	1-2	1	1	1
Möglichkeit der Auswaschung	5	2-4	1	0	0	5
Pflanzen						
Getreide	3-4	4-5	0	4-5	1	5
Reis	5	2-4	0	0	0	1-2
Zuckerrohr	2-4	3-5	5	3-5	1	5
Baumwolle	3-5	3-5	5	3-5	2-4	5
Hackfrüchte	2-4	3-5	5	5	1	5
Gemüse	2-4	3-5	3-5	5	5	5
Futterpflanzen	5	5	1-3	5	1	5
Grünland	5	5	0	5	0	5
Baumwollkulturen	5	1-3	3-5	2-4	5	5
Rebanlagen	2-4) ³	2-4) ³	3-5	2-4) ³	5	5
Arbeit und Technik						
Handarbeit	3-5	2-4	2-4	1	1-3	1-4
technisches Verständnis	1-2	1-2	1-2	2-4	2-4	3-5
Möglichkeit der Automation	1	1	1	5	5	5
Mehrzweckverwendung	1	1	1	2-4	2-4	3-5
Maschineneinsatz	1-2	2-4	2-4	5	3-5	3-5
Anlage und Betrieb						
Geländeverlust	3-5	2-4	1-3	0	1-2	1
Materialbedarf	1	1	1	5	5	5
Energiebedarf	0-2	0-2	0-2	3-4	3-4	5
Wartungsaufwand	1	1	1	1-2	2-3	3-4
Anlagekosten	1-3	1-3	1-3	5	4	5
Betriebskosten	2-3	2-3	2-3	3-4	3-4	5

¹ Unterflurrieselung (nicht Anhebung des Grundwasserstandes)

² auf Terrassen bzw. Konturfurchen

³ in ebenem Gelände

Die Beurteilung erfolgt innerhalb von 6 Bewertungsstufen:

0 = nicht möglich, ungeeignet, unbedeutend

1 = kaum möglich, kaum geeignet, sehr gering, klein, niedrig

5 = sehr gut möglich, sehr gut geeignet, sehr gut, groß, hoch

5. optimization of the tool

5.1 parameter: possibility of irrigation with a big amount of water

User selection for the possibility of irrigation with a big amount of water

The user of the tool has to choose one of the following characterizations for the parameter possibility of irrigation with a big amount of water for his field:

The possibility of irrigation with a big amount of water should be:

- given
- not given
- not relevant

The selection of the user characterization will be with a drop down menu in the tool.

Calculation of the recommendation matrix for the possibility of irrigation with a big amount of water

The recommendation table from Achtnich, see Table 12, has a recommendation point for every irrigation method for the possibility of irrigation with a big amount of water. These points are written in a table below:

Table 13 recommendation points for the possibility of irrigation with a big amount of water

irrigation method	basin	strip	furrow	drainage	drip	sprinkler
points	5	4	3	2-4	2-4	5

The points which are given in a range will be averaged and written in a vector as below:

$$(5 \ 4 \ 3 \ 3 \ 3 \ 5)$$

The points in Table 12 are in the opposite convention as in the tool. The point 0 means a bad rating and 5 means a good rating. In the tool 0 means a good rating and 5 a bad rating. For this reason the points from Table 12 must be converted to the convention in the tool as shown below:

$$\textit{point in the tool} = 5 - \textit{point in Table 12}$$

5. optimization of the tool

With that a new vector as shown below can be calculated:

$$(0 \ 1 \ 2 \ 2 \ 2 \ 0)$$

The points in the vector will be used for the user characterization “given” from the drop down menu. The user selection “not given” will be calculated with the factor 0, because if the parameter is not needed it should not affect the recommendation. The user characterization “not relevant” will be calculated with the factor 0, because it is not relevant for the recommendation.

With these assumptions it is possible to calculate the following recommendation matrix:

$$(1 \ 0 \ 0) \times \begin{pmatrix} 0 & 1 & 2 & 2 & 2 & 0 \\ 0 & 1 & 2 & 2 & 2 & 0 \\ 0 & 1 & 2 & 2 & 2 & 0 \end{pmatrix} = \begin{pmatrix} 0 & 1 & 2 & 2 & 2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

So that the following recommendation matrix for the parameter possibility of irrigation with a big amount of water can be programmed to excel:

$$\begin{pmatrix} 0 & 1 & 2 & 2 & 2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

5.2 parameter: possibility of irrigation with a small amount of water

User selection for the possibility of irrigation with a small amount of water

The user of the tool has to choose one of the following characterizations for the parameter possibility of irrigation with a small amount of water for his field:

The possibility of irrigation with a small amount of water should be:

- given
- not given
- not relevant

The selection of the user characterization will be with a drop down menu in the tool.

5. optimization of the tool

Calculation of the recommendation matrix for the possibility of irrigation with a small amount of water

The recommendation table from Achtnich, see Table 12, has a recommendation point for every irrigation method for the possibility of irrigation with a small amount of water. These points are written in a table below:

Table 14 recommendation points for the possibility of irrigation with a small amount of water

irrigation method	basin	strip	furrow	drainage	drip	sprinkler
points	0	0	0	2-4	5	5

The points which are given in a range will be averaged and written in a vector as below:

$$(0 \ 0 \ 0 \ 3 \ 5 \ 5)$$

The points in Table 12 are in the opposite convention as in the tool. The point 0 means a bad rating and 5 means a good rating. In the tool 0 means a good rating and 5 a bad rating. For this reason the points from Table 12 must be converted to the convention in the tool as shown below:

$$\textit{point in the tool} = 5 - \textit{point in Table 12}$$

With that a new vector as shown below can be calculated:

$$(5 \ 5 \ 5 \ 2 \ 0 \ 0)$$

The points in the vector will be used for the user characterization “given” from the drop down menu. The user selection “not given” will be calculated with the factor 0, because if the parameter is not needed it should not affect the recommendation. The user characterization “not relevant” will be calculated with the factor 0, because it is not relevant for the recommendation.

5. optimization of the tool

With these assumptions it is possible to calculate the following recommendation matrix:

$$(1 \ 0 \ 0) \times \begin{pmatrix} 5 & 5 & 5 & 2 & 0 & 0 \\ 5 & 5 & 5 & 2 & 0 & 0 \\ 5 & 5 & 5 & 2 & 0 & 0 \end{pmatrix} = \begin{pmatrix} 5 & 5 & 5 & 2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

So that the following recommendation matrix for the parameter possibility of irrigation with a small amount of water can be programmed to excel:

$$\begin{pmatrix} 5 & 5 & 5 & 2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

5.3 parameter: uniformly water distribution

User selection for uniformly water distribution

The user of the tool has to choose one of the following characterizations for the parameter uniformly water distribution for his field:

Uniformly water distribution should be:

- given
- not given
- not relevant

The selection of the user characterization will be with a drop down menu in the tool.

Calculation of the recommendation matrix for uniformly water distribution

The recommendation table from Achtnich, see Table 12, has a recommendation point for every irrigation method for the uniformly water distribution. These points are written in a table below:

Table 15 recommendation points for uniformly water distribution

irrigation method	basin	strip	furrow	drainage	drip	sprinkler
points	2-4	2-4	3-5	5	5	3-5

5. optimization of the tool

The points which are given in a range will be averaged and written in a vector as below:

$$(3 \ 3 \ 4 \ 5 \ 5 \ 4)$$

The points in Table 12 are in the opposite convention as in the tool. The point 0 means a bad rating and 5 means a good rating. In the tool 0 means a good rating and 5 a bad rating. For this reason the points from Table 12 must be converted to the convention in the tool as shown below:

$$\textit{point in the tool} = 5 - \textit{point in Table 12}$$

With that a new vector as shown below can be calculated:

$$(2 \ 2 \ 1 \ 0 \ 0 \ 1)$$

The points in the vector will be used for the user characterization “given” from the drop down menu. The user selection “not given” will be calculated with the factor 0, because if the parameter is not needed it should not affect the recommendation. The user characterization “not relevant” will be calculated with the factor 0, because it is not relevant for the recommendation.

With these assumptions it is possible to calculate the following recommendation matrix:

$$(1 \ 0 \ 0) \times \begin{pmatrix} 2 & 2 & 1 & 0 & 0 & 1 \\ 2 & 2 & 1 & 0 & 0 & 1 \\ 2 & 2 & 1 & 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} 2 & 2 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

So that the following recommendation matrix for uniformly water distribution can be programmed to excel:

$$\begin{pmatrix} 2 & 2 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

5.4 parameter: usage of saline water

User selection for usage of saline water

The user of the tool has to choose one of the following characterizations for the parameter usage of saline water for his field:

Usage of saline water should be:

- possible
- not possible
- not relevant

The selection of the user characterization will be with a drop down menu in the tool.

Calculation of the recommendation matrix for usage of saline water

The recommendation table from Achtnich, see Table 12, has a recommendation Point for every irrigation method for the usage of saline water. These points are written in a table below:

Table 16 recommendation points for usage of saline water

irrigation method	basin	strip	furrow	drainage	drip	sprinkler
points	2-4	1-2	1-2	1	1	1

The points which are given in a range will be averaged and written in a vector as below:

$$(3 \quad 1,5 \quad 1,5 \quad 1 \quad 1 \quad 1)$$

The points in Table 12 are in the opposite convention as in the tool. The point 0 means a bad rating and 5 means a good rating. In the tool 0 means a good rating and 5 a bad rating. For this reason the points from Table 12 must be converted to the convention in the tool as shown below:

$$point \text{ in the tool} = 5 - \text{pont in Table 12}$$

With that a new vector as shown below can be calculated:

$$(2 \quad 3,5 \quad 3,5 \quad 4 \quad 4 \quad 4)$$

5. optimization of the tool

The points in the vector will be used for the user characterization “possible” from the drop down menu. The user selection “not possible” will be calculated with the factor 0, because if the parameter is not needed it should not affect the recommendation. The user characterization “not relevant” will be calculated with the factor 0, because it is not relevant for the recommendation.

With these assumptions it is possible to calculate the following recommendation matrix:

$$(1 \ 0 \ 0) \times \begin{pmatrix} 2 & 3,5 & 3,5 & 4 & 4 & 4 \\ 2 & 3,5 & 3,5 & 4 & 4 & 4 \\ 2 & 3,5 & 3,5 & 4 & 4 & 4 \end{pmatrix} = \begin{pmatrix} 2 & 3,5 & 3,5 & 4 & 4 & 4 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

So that the following recommendation matrix for the usage of saline water can be programmed to excel:

$$\begin{pmatrix} 2 & 3,5 & 3,5 & 4 & 4 & 4 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

5.5 parameter: technical understanding

User selection for technical understanding

The user of the tool has to choose one of the following characterizations for the parameter technical understanding:

Technical understanding is:

- existing
- not existing
- not relevant

The selection of the user characterization will be with a drop down menu in the tool.

5. optimization of the tool

Calculation of the recommendation matrix for technical understanding

The recommendation table from Achtnich, see Table 12, has a recommendation point for every irrigation method for the technical understanding. These points are written in a table below:

Table 17 recommendation points for technical understanding

irrigation method	basin	strip	furrow	drainage	drip	sprinkler
points	1-2	1-2	1-2	2-4	2-4	3-5

The points which are given in a range will be averaged and written in a vector as below:

$$(1,5 \quad 1,5 \quad 1,5 \quad 3 \quad 3 \quad 4)$$

The points in Table 12 are in the opposite convention as in the tool. The point 0 means a bad rating and 5 means a good rating. In the tool 0 means a good rating and 5 a bad rating. For this reason the points from Table 12 must be converted to the convention in the tool as shown below:

$$\textit{point in the tool} = 5 - \textit{point in Table 12}$$

With that a new vector as shown below can be calculated:

$$(3,5 \quad 3,5 \quad 3,5 \quad 2 \quad 2 \quad 1)$$

The points in the vector will be used for the user characterization “existing” from the drop down menu. The user selection “not existing” will be calculated with the factor 0, because if the parameter is not needed it should not affect the recommendation. The user characterization “not relevant” will be calculated with the factor 0, because it is not relevant for the recommendation.

5. optimization of the tool

With these assumptions it is possible to calculate the following recommendation matrix:

$$(1 \ 0 \ 0) \times \begin{pmatrix} 3,5 & 3,5 & 3,5 & 4 & 4 & 4 \\ 3,5 & 3,5 & 3,5 & 4 & 4 & 4 \\ 3,5 & 3,5 & 3,5 & 4 & 4 & 4 \end{pmatrix} = \begin{pmatrix} 3,5 & 3,5 & 3,5 & 4 & 4 & 4 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

So that the following recommendation matrix for the technical understanding can be programmed to excel:

$$\begin{pmatrix} 3,5 & 3,5 & 3,5 & 4 & 4 & 4 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

5.6 parameter: possibility of automation

User selection for possibility of automation

The user of the tool has to choose one of the following characterizations for the parameter possibility of automation:

Possibility of automation should be:

- given
- not given
- not relevant

The selection of the user characterization will be with a drop down menu in the tool.

Calculation of the recommendation matrix for possibility of automation

The recommendation table from Achtnich, see Table 12, has a recommendation point for every irrigation method for the possibility of automation. These points are written in a table below:

Table 18 recommendation points for possibility of automation

irrigation method	basin	strip	furrow	drainage	drip	sprinkler
points	1	1	1	5	5	5

5. optimization of the tool

The points which are given in a range will be averaged and written in a vector as below:

$$(1 \ 1 \ 1 \ 5 \ 5 \ 5)$$

The points in Table 12 are in the opposite convention as in the tool. The point 0 means a bad rating and 5 means a good rating. In the tool 0 means a good rating and 5 a bad rating. For this reason the points from Table 12 must be converted to the convention in the tool as shown below:

$$\textit{point in the tool} = 5 - \textit{point in Table 12}$$

With that a new vector as shown below can be calculated:

$$(4 \ 4 \ 4 \ 0 \ 0 \ 0)$$

The points in the vector will be used for the user characterization “given” from the drop down menu. The user selection “not given” will be calculated with the factor 0, because if the parameter is not needed it should not affect the recommendation. The user characterization “not relevant” will be calculated with the factor 0, because it is not relevant for the recommendation.

With these assumptions it is possible to calculate the following recommendation matrix:

$$(1 \ 0 \ 0) \times \begin{pmatrix} 4 & 4 & 4 & 0 & 0 & 0 \\ 4 & 4 & 4 & 0 & 0 & 0 \\ 4 & 4 & 4 & 0 & 0 & 0 \end{pmatrix} = \begin{pmatrix} 4 & 4 & 4 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

So that the following recommendation matrix for the possibility of automation can be programmed to excel:

$$\begin{pmatrix} 4 & 4 & 4 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

5.7 parameter: usage of machinery

User selection for usage of machinery

The user of the tool has to choose one of the following characterizations for the parameter usage of machinery:

Usage of machinery should be:

- possible
- not possible
- not relevant

The selection of the user characterization will be with a drop down menu in the tool.

Calculation of the recommendation matrix for usage of machinery

The recommendation table from Achtnich, see Table 12, has a recommendation point for every irrigation method for the usage of machinery. These points are written in a table below:

Table 19 recommendation points for usage of machinery

irrigation method	basin	strip	furrow	drainage	drip	sprinkler
points	1-2	2-4	2-4	5	3-5	3-5

The points which are given in a range will be averaged and written in a vector as below:

$$(1,5 \quad 3 \quad 3 \quad 5 \quad 4 \quad 4)$$

The points in Table 12 are in the opposite convention as in the tool. The point 0 means a bad rating and 5 means a good rating. In the tool 0 means a good rating and 5 a bad rating. For this reason the points from Table 12 must be converted to the convention in the tool as shown below:

$$\textit{point in the tool} = 5 - \textit{point in Table 12}$$

With that a new vector as shown below can be calculated:

$$(3,5 \quad 2 \quad 2 \quad 0 \quad 1 \quad 1)$$

5. optimization of the tool

The points in the vector will be used for the user characterization “possible” from the drop down menu. The user selection “not possible” will be calculated with the factor 0, because if the parameter is not needed it should not affect the recommendation. The user characterization “not relevant” will be calculated with the factor 0, because it is not relevant for the recommendation.

With these assumptions it is possible to calculate the following recommendation matrix:

$$(1 \ 0 \ 0) \times \begin{pmatrix} 3,5 & 2 & 2 & 0 & 1 & 1 \\ 3,5 & 2 & 2 & 0 & 1 & 1 \\ 3,5 & 2 & 2 & 0 & 1 & 1 \end{pmatrix} = \begin{pmatrix} 3,5 & 2 & 2 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

So that the following recommendation matrix for the usage of machinery can be programmed to excel:

$$\begin{pmatrix} 3,5 & 2 & 2 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

5.8 parameter: ground lost

User selection for ground lost

The user of the tool has to choose one of the following characterizations for the parameter ground lost

Ground lost is:

- acceptable
- not acceptable
- not relevant

The selection of the user characterization will be with a drop down menu in the tool.

5. optimization of the tool

Calculation of the recommendation matrix for ground lost

The recommendation table from Achtnich, see Table 12, has a recommendation point for every irrigation method for the ground lost. These points are written in a table below:

Table 20 recommendation points for ground lost

irrigation method	basin	strip	furrow	drainage	drip	sprinkler
points	3-5	2-4	1-3	0	1-2	1

The points which are given in a range will be averaged and written in a vector as below:

$$(4 \quad 3 \quad 2 \quad 0 \quad 1,5 \quad 1)$$

The points in the vector will be used for the user characterization “not acceptable” from the drop down menu. The user selection “acceptable” will be calculated with the factor 0, because if the parameter is not needed it should not affect the recommendation. The user characterization “not relevant” will be calculated with the factor 0, because it is not relevant for the recommendation.

With these assumptions it is possible to calculate the following recommendation matrix:

$$(0 \quad 1 \quad 0) \times \begin{pmatrix} 4 & 3 & 2 & 0 & 1,5 & 1 \\ 4 & 3 & 2 & 0 & 1,5 & 1 \\ 4 & 3 & 2 & 0 & 1,5 & 1 \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 4 & 3 & 2 & 0 & 1,5 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

So that the following recommendation matrix for the ground lost can be programmed to excel:

$$\begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 4 & 3 & 2 & 0 & 1,5 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

5.9 parameter: water dosage

User selection for water dosage

The user of the tool has to choose one of the following characterizations for the parameter water dosage for his field:

Water dosage should be:

- possible
- not possible
- not relevant

The selection of the user characterization will be with a drop down menu in the tool.

Calculation of the recommendation matrix for the water dosage

The recommendation from Achtnich, see Table 12, has a recommendation point for every irrigation method for the water dosage. These points are written in a table below:

Table 21 recommendation points for the water dosage

irrigation method	basin	strip	furrow	drainage	drip	sprinkler
points	3	3	3	5	5	5

The points are written in a vector as below:

$$(3 \ 3 \ 3 \ 5 \ 5 \ 5)$$

The points in Table 12 are in the opposite convention as in the tool. The point 0 means a bad rating and 5 means a good rating. In the tool 0 means a good rating and 5 a bad rating. For this reason the points from Table 12 must be converted to the convention in the tool as shown below:

$$point \ in \ the \ tool = 5 - point \ in \ Table \ 12$$

With that a new vector as shown below can be calculated:

$$(2 \ 2 \ 2 \ 0 \ 0 \ 0)$$

The points in the vector will be used for the user characterization “possible” from the drop down menu. The user selection “not possible” will be calculated with the factor 0, because if the parameter is not needed it

5. optimization of the tool

should not affect the recommendation. The user characterization "not relevant" will be calculated with the factor 0, because it is not relevant for the recommendation.

With these assumptions it is possible to calculate the following recommendation matrix:

$$(1 \ 0 \ 0) \times \begin{pmatrix} 2 & 2 & 2 & 0 & 0 & 0 \\ 2 & 2 & 2 & 0 & 0 & 0 \\ 2 & 2 & 2 & 0 & 0 & 0 \end{pmatrix} = \begin{pmatrix} 2 & 2 & 2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

So that the following recommendation matrix for the water dosage can be programmed to excel:

$$\begin{pmatrix} 2 & 2 & 2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

5.10 parameter: loamy sand

User selection for loamy sand

The user of the tool has to choose one of the following characterizations for the parameter loamy sand:

Loamy sand is:

- existing
- not existing
- not relevant

The selection of the user characterization will be with a drop down menu in the tool.

Calculation of the recommendation matrix for loamy sand

The recommendation table from Achtnich, see Table 12, has a recommendation point for every irrigation method for loamy sand. These points are written in a table below:

5. optimization of the tool

Table 22 recommendation points for loamy sand

irrigation method	basin	strip	furrow	drainage	drip	sprinkler
points	3-5	2-4	2-4	3-5	5	5

The points which are given in a range will be averaged and written in a vector as below:

$$(4 \ 3 \ 3 \ 4 \ 5 \ 5)$$

The points in Table 12 are in the opposite convention as in the tool. The point 0 means a bad rating and 5 means a good rating. In the tool 0 means a good rating and 5 a bad rating. For this reason the points from Table 12 must be converted to the convention in the tool as shown below:

$$\textit{point in the tool} = 5 - \textit{point in Table 12}$$

With that a new vector as shown below can be calculated:

$$(1 \ 2 \ 2 \ 1 \ 0 \ 0)$$

The points in the vector will be used for the user characterization “existing” from the drop down menu. The user selection “not existing” will be calculated with the factor 0, because if the parameter is not needed it should not affect the recommendation. The user characterization “not relevant” will be calculated with the factor 0, because it is not relevant for the recommendation.

With these assumptions it is possible to calculate the following recommendation matrix:

$$(1 \ 0 \ 0) \times \begin{pmatrix} 1 & 2 & 2 & 1 & 0 & 0 \\ 1 & 2 & 2 & 1 & 0 & 0 \\ 1 & 2 & 2 & 1 & 0 & 0 \end{pmatrix} = \begin{pmatrix} 1 & 2 & 2 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

5. optimization of the tool

So that the following recommendation matrix for loamy sand can be programmed to excel:

$$\begin{pmatrix} 1 & 2 & 2 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

5.11 parameter: clayey loam

User selection for clayey loam

The user of the tool has to choose one of the following characterizations for the parameter clayey loam:

Clayey loam is:

- existing
- not existing
- not relevant

The selection of the user characterization will be with a drop down menu in the tool.

Calculation of the recommendation matrix for clayey loam

The recommendation table from Achtnich, see Table 12, has a recommendation point for every irrigation method for clayey loam. These points are written in a table below:

Table 23 recommendation points for clayey loam

irrigation method	basin	strip	furrow	drainage	drip	sprinkler
points	5	3-5	3-5	3-5	5	3-5

The points which are given in a range will be averaged and written in a vector as below:

$$(5 \ 4 \ 4 \ 4 \ 5 \ 4)$$

The points in Table 12 are in the opposite convention as in the tool. The point 0 means a bad rating and 5 means a good rating. In the tool 0

5. optimization of the tool

means a good rating and 5 a bad rating. For this reason the points from Table 12 must be converted to the convention in the tool as shown below:

$$\text{point in the tool} = 5 - \text{point in Table 12}$$

With that a new vector as shown below can be calculated:

$$(0 \ 1 \ 1 \ 1 \ 0 \ 1)$$

The points in the vector will be used for the user characterization “existing” from the drop down menu. The user selection “not existing” will be calculated with the factor 0, because if the parameter is not needed it should not affect the recommendation. The user characterization “not relevant” will be calculated with the factor 0, because it is not relevant for the recommendation.

With these assumptions it is possible to calculate the following recommendation matrix:

$$(1 \ 0 \ 0) \times \begin{pmatrix} 0 & 1 & 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 1 & 0 & 1 \end{pmatrix} = \begin{pmatrix} 0 & 1 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

So that the following recommendation matrix for clayey loam can be programmed to excel:

$$\begin{pmatrix} 0 & 1 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

All the new recommendation matrixes from Chapter 5 are built in the tool, so that the optimized tool can give a better recommendation for an irrigation system that fits the best to the field, according to the entered parameters from the user input.

6. practice under real conditions

Voluntarily I flew to Nicaragua and did an interview with a local farmer about his farming with solar based irrigation system. Also I wanted to see what the real conditions are that the farmers have to deal with every day in Nicaragua and I wanted to prove that the theoretically programmed optimized tool in this thesis works also under real conditions.

6.1 Interview

Before I flew to Nicaragua I had contact with a local company in Leon named “Enicalsa”, which is a company for solar based irrigation systems. Together with the Manager of Enicalsa I found a farmer to do the interview with and who has good records of his farming data.

What follows is a written summary of my interview with the farmer Juan del Dios at the 05/05/2015 from 9:54-10:37 AM in La Ceiba in the suburban of Leon, Nicaragua. The whole interview can be seen in the Appendix.

Juan del Dios is 59 years old and lives in La Ceiba which is a suburban of Leon, the second biggest city in Nicaragua. Juan is born and raised in Leon (Nicaragua) and he has always lived in Leon.



Figure 14 Juan (left) with one of his workmen

His father was a farmer, so he grew up in contact with agriculture in his childhood. He finished the primary school, which is 6 years in Nicaragua.

6. practice under real conditions

After he grew up, he worked as a workman in agriculture for ten years and with this experience he started to work as a self-employed farmer.

Juan got a field in the time of the revolution in Nicaragua in 1979. In this year the dictatorship was overthrown by the resistance movement “Frente Sandinista de Liberación Nacional”. And one of the reformations after the resistance movement took over the power was to distribute some of the fields of the large landowners evenly to the general population.

Juan is working on his field self-employed since 30 years now. He has a wife who takes care of the household. The two grown up children of Juan do not live in the same house as him anymore. They both completed their studies. One of them is a pharmacist and the other one finished the business administration school. Juan needs around 800US\$ for a year for himself and his wife’s living expenses and for the expenses for his own business. The expenses are fluctuating, in the summer (November - April) the expenses are more and in the winter (May - October) the expenses are less. The “Finca” where Juan and his wife live is owned by himself.



Figure 15 Juans finca

On his Finca he has a field of 25 “Manzanas” (17.5 hectare). He is owner of 20 Manzanas of the 25 Manzanas, the rest is leased. He grows 35 plants of papayas, beans, bananas, 2 Manzanas of corn and one Manzana of watermelons.



Figure 16 corn field



Figure 17 banana plants

The papayas, the corn and the watermelons are grown to sell them. The beans and the bananas are mostly for his own usage. Additionally he works as a cattle farmer. He has 40-45 cows, 70 chickens, 3 Horses, 3 Pigs, 2 turkeys and 3 ducks. He gets milk form the cows to sell on the market and he also sells two or three of the cows per year to make money.



Figure 18 cattle farm



Figure 19 turkeys and chicken

To operate the fields he needs 4 workmen. They are working 4 hours per day all year around. In the year 2007 a photovoltaic system with a pump and a drip irrigation was installed. Additionally Juan has a water tank with the capacity of 750 liters.



Figure 20 photovoltaic panels



Figure 21 well



Figure 22 water tank

The pump is running 8 hours per day. 20% of the pumped water is needed for personal use by Juan and his family. 40% of the water is for irrigation of the fields and 40% is for his cattle. Before the installation of the system he needed 2-3 workers and one horse to pull water out of the well, so the water could be used to irrigate the plants. After the installation of the system the workers who were needed to pull the water up could work on the field, so that the productivity could be increased. Additionally the electricity expenses could be reduced. Before the installation of the system Juan could only cover the vital needs for himself and his family. After the installation of the system he could also make profit. The profit is around 1500 US\$ per year (Income per capita in Nicaragua: around 1.850 US-Dollar (2014) according to the ministry of foreign affair). Before the installation of the sys-

6. practice under real conditions

tem he had to work 12 hours per day at seven days a week. After the installation of the system his working time was reduced to 6 hours per day.

After the installation of the system, Juan was able to grow the high water consuming papaya plant. Before the installation it was almost not possible, because the water that the workers could pull up of the well was not enough for watering the papayas. Now Juan can sell the papayas very good on the Market of Leon, because the most of the other farmers do not have an installed system like Juan has and they cannot grow papaya. So he can sell the papayas for more money, because the demand is high and the supply is low.



Figure 23 papaya plants

Before the installation of the system Juan had more crop failures because of lack of water, which changed after the installation of the system. The quantity and the quality of the crops increased, so that Juan could sell his products for more money on the markets.

Juan gets more money for his crops after the installation of the system. With this money Juan is investing in his own business but also in the increasing of his personal quality of life. He invested more in irrigation technology and built a new fence for his business. He bought a television, a refrigerator and invested in his house.



Figure 24 terrace

Juan realized that his household is one of the few in his town who had a refrigerator. So he started to sell cooled drinks and ice-cream. With his idea he generated a small new source of income for himself.

This year Juan wanted to start growing watermelon on a big field, because he thinks they are easy to handle and he can make a lot money with it. He thinks that he could not grow them on a big field without the installed system. The following calculation was shown to us by Juan himself:

Juan has 1650 irrigation holes from the installed system on his field. In every irrigation hole there are 3 watermelon seeds in it. Juan guesses that only 2 seeds will survive in every hole. So he will have 3300 Watermelon plants. Every plant will give him around 5 Watermelons. So he will get 16500 Watermelons from the crop. Juan will sell them for 20C\$ at the markets. So he will get 33000C\$ (Around 12360US\$).



Figure 25 just planted watermelons

6.2 practice of the optimized tool

The data that I collected on Juan's field is listed below, with this data an example usage of the optimize tool will be shown in this chapter.

For the input for the tool the field parameters of chapter 5 were needed. The existing parameters on Juan's field are shown bold in the following lists. With the help of a geography student the following data was collected from the field of Juan:

the soil slope is:

- **plane**
- moderate slope
- high slope
- not relevant

ground lost is:

- **acceptable**
- not acceptable
- not relevant

loamy sand is:

- existing
- **not existing**
- not relevant

clayey loam is:

- existing
- **not existing**
- not relevant

the risk of erosion of the soil is:

- low
- **medium**
- high
- not relevant

6. practice under real conditions

the salinization of the soil is:

- low
- **medium**
- high
- not relevant

the possibility of leaching is:

- low
- **medium**
- high
- not relevant

the risk of water losses are:

- low
- medium
- **high**
- not relevant

the possibility of irrigation with a big amount of water should be:

- given
- **not given**
- not relevant

the possibility of irrigation with a small amount of water should be:

- **given**
- not given
- not relevant

water dosage should be:

- **possible**
- not possible
- not relevant

uniformly water distribution should be:

- given
- **not given**
- not relevant

6. practice under real conditions

usage of saline water should be:

- possible
- **not possible**
- not relevant

energy resources are:

- **given**
- not given
- not relevant

the initial budget is:

- **low**
- medium
- high
- not relevant

the annual Budget is:

- **low**
- medium
- high
- not relevant

technical understanding is:

- existing
- **not existing**
- not relevant

possibility of automation should be:

- given
- **not given**
- not relevant

usage of machinery should be:

- **possible**
- not possible
- not relevant

6. practice under real conditions

This data will be the input of the optimized tool and will be filled in the dropdown menus of the local field parameters in the tool, see Figure 26.

print
reset

local field parameters

soil slope is:	1	plane	▼
ground lost is:	1	acceptable	▼
loamy sand is:	2	not existing	▼
clayey loam is:	2	not existing	▼
risk of erosion of the soil is:	2	medium	▼
salinization of the soil is:	2	medium	▼
possibility of leaching is:	2	medium	▼
risk of water losses are:	3	high	▼
possibility of irrigation with small amount of water should be:	2	not given	▼
possibility of irrigation with big amount of water should be:	1	given	▼
water dosage should be:	1	possible	▼
uniformly water distribution should be:	2	not given	▼
usage of saline water should be:	2	not possible	▼
energy resources are:	1	given	▼
initial budget is:	1	low	▼
annual budget is:	1	low	▼
technical understanding:	2	not existing	▼
possibility of automation should be:	2	not given	▼
usage of machinery should be:	2	not possible	▼

Figure 26 Juan's local field parameters

With these local field parameters the optimized tool will calculate which irrigation method that fits the best to the field of Juan and show the name and picture of that method. A diagram with some other of the high-rated recommendations will also be visible. In the case of Juan the drip irrigation was recommended, see Figure 27.

6. practice under real conditions

recommendation of the irrigation method
drop irrigation

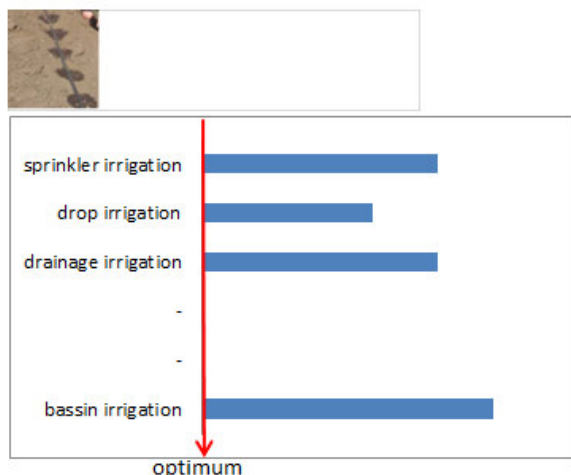


Figure 27 recommended irrigation system for the field of Juan

For the recommendation of a generator more data is needed. These data's are from Juan's records and are just filled in the table.

currency	dollar		photovoltaic	power station	wind energy	other
investment costs generator			3000	450		
investmenst cost pump			2700	2700		
investent costs irrigation method			900	900		
interest rate			27,50%	27,50%		
repayment term			6	6		
wage costs/year			30	60		
fuel/year				1300		
spare parts/year			20	95		
service and repair/year			30	60		
wind speed average m/s			3,5			
solar radiation kwh/m ²			1100			

Figure 28 Juan's generator data

The wind energy generator is automatically out of the recommendation from the tool, because the average wind speed in Leon is too low to run a wind generator (for more details see chapter 3.4.3).

After this the tool will calculate the cost for each system in each year the system is running and show a table and a chart with these data, see Figure 29 and Figure 30.

total costs										
year	1	2	3	4	5	6	7	8	9	10
photovoltaic	2995	5687,5	8077,5	10165	11950	13432,5	13512,5	13592,5	13672,5	13752,5
power station	3303,75	6421,875	9354,375	12101,25	14662,5	17038,125	18553,125	20068,125	21583,125	23098,125
wind energy										
other										

Figure 29 costs for the generator (table)

6. practice under real conditions



Figure 30 cost for the generator (chart)

According to this data the tool will make a recommendation. The recommendation will be for the cheapest generator which can run the system on the field of the farmer.

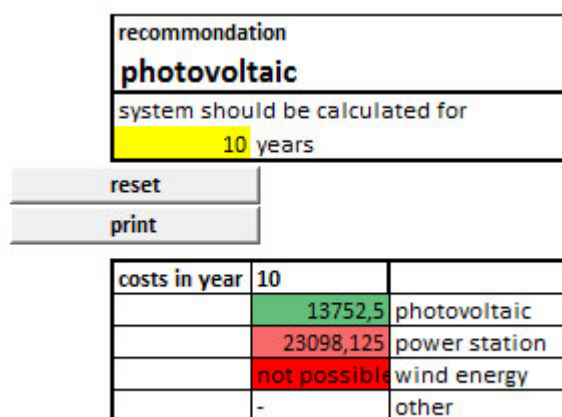


Figure 31 Juan's recommendation of the generator

In the case of Juan the photovoltaic generator is recommended, because it is the cheapest one that can run the irrigation system.

The tool will show a printable summary of the recommendations and the total costs of the irrigation system, see Figure 32.

6. practice under real conditions

irrigation method			<input type="button" value="print"/>
drip irrigation			
generator			
photovoltaic			
total costs of the irrigation system			
13752,5	dollar	incl. 10	years credit cost.

Figure 32 summary of recommendations

The tool will also show a chart with plants and how suitable the plants are for the recommended irrigation system, see Figure 33.

suitable plants for cultivation with the shown irrigation system	
cereals	barely suitable
rice	unsuitable
sugarcane	barely suitable
cotton	limited suitable
root corps	barely suitable
vegetables	very good suitable
fodder plants	barely suitable
grassland	unsuitable
cotton corps	very good suitable
vineyards	very good suitable

Figure 33 suitable plants

The recommended system is installed on the field of Juan since 2007. Before the installation of the system Juan was only able to cover his needs. Since the installation of the systems Juan can make profit every year. With the solar based drip farming system he can expand his business and increase his personal quality of life.

7. summary

The objective of this master thesis was the optimization of the tool which was developed in the bachelor thesis (*Development of a tool for recommendation of irrigation systems based on local parameters, 2013*).

In the beginning of this thesis it was shown that there is no unique irrigation system which can be used on every field. And that every irrigation system for a field must be set by local field parameters, so that the discussed ecological, social and agricultural problems on earth can be minimized.

The structure of irrigation systems was presented and the detailed advantages and disadvantages of different kinds of parts of irrigation systems were shown. It was shown that it is very complicated to find a fitting irrigation system for a field manually.

The already existing tool from the bachelor thesis was presented and explained. It was shown that an optimization is needed for a better recommendation of irrigation systems.

11 new field parameters were programmed in the tool to optimize the existing tool and to make the recommendation more effective. The programming was explained for every parameter in the thesis. The input was made easier with dropdown lists. The output was simplified with pictures. Also print buttons and reset buttons were installed in the tool to make the tool easier to use.

A practice usage of the optimized tool with real field parameters of a farmer from Nicaragua was demonstrated. It proved that the tool also works under real conditions. This farmer was portrayed at an interview that can be found in the appendix.

Additionally, a movie about building up solar based drip irrigation systems in Nicaragua was made voluntarily during the 3 weeks research visit for this master thesis in Leon, Nicaragua. The interview was also summarized in the movie.

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Appendix

Written Interview with the farmer Juan del Dios at 05/05/2015 from 9:54-10:37 AM in La Ceiba in the suburban of Leon, Nicaragua

General questions and social situation

What is your name and how old are you?

My name is Juan del Dios and I am 59 years old.

Where were you born and raised, did you ever live somewhere else?

I am born and raised in Leon and lived here all my life till now.

What was the occupation of your father?

My father was a farmer.

How many years did you go to school?

I finished the primary school here in Leon. So 6 years.

How many years have you been working in farming and what kind of other work experience do you have?

I have 40 years of work experience in farming, 10 years as a workman and 30 years as a self-employed farmer.

What kind of other jobs do you have except as a farmer?

I am also a cattle farmer.

How many working hours did you have before the installation of the irrigation system and how many working hours do you have now, after the installation of the irrigation system?

I had to work 12 hours a day in 7 days a week, before the installation of the irrigation system. I am working 6 hours at 7 days in a week now, after the installation.

How many people do you have to feed and what are the other people doing?

I have one wife and two children. But my children are not living here anymore. They finished their studies. One of them is working in business administration and the other one is a pharmacist and they have their own households.

My wife is taking care of the household.

Is the finca and the field your property?

Yes, the finca and 20 of the 25 Manzanas are my property.

Is the work that you are doing for the nutrition of your family or are you also making profit with it?

Before the installation of the irrigation system my work was only for our own captive use. After the installation of the irrigation system I also made profit with my work.

How much time of a day do you spend time for business purposes and how much time for private purposes? And what are you doing in your spare time?

Before the installation of the irrigation system I spent 2 hours a day for business purposes and after the installation I am spending only 6 hours for business purposes, the rest of the day I have free time.

In my free time I am going to drink a couple of beers with my friends. I am visiting my mother. I am also going to church and meet my friends.

Finances

Is the annual/monthly income fluctuating? How was it before the installation of the irrigation system and how is it after?

Yes the annual income after the installation of the irrigation system is more fluctuating then before the installation.

In the months November till January the income is more than the average, the other months the income is less and sometimes there is almost no income.

How much is the average profit in a year? Was there a difference before and after the installation of the irrigation system?

Before the installation of the irrigation system there was almost no profit, after the installation of the irrigation system the profit is in average around 1500US\$ in a year.

The irrigation system replaced 2 or 3 workmen, which were needed to bring the water from the well to the field. These workmen are working on the fields now, so that I can reach a better productivity.

How much is the average living expenses per year everything included for work and family?

I am spending around 800US\$ everything included per year (staff, food, medicine...). The living expenses are fluctuating too. In the summer and dry season the living expenses are higher, in the rain season and winter the living expenses are less.

Business

How many workmen do you have and are the amount of them fluctuating in dry and rain season?

I have 4 workmen, they are working 4 hours every day in the year, no matter if we have rain or dry season.

What is the field area of your finca and how much is irrigated now?

I have 25 Manzanas area on my finca, 1 Manzana is irrigated now.

What are you using the water that comes from the pump of your system for? Can you give me a percentage of the usage?

The pump is running around 8 hours per day. The water from the pump is used 20% for the personal use, 40% is used for field irrigation and 40% is used for my cattle farm.

What plants do you have on your field, on what area or which amount? Are there any changes before and after the installation of the irrigation system? Can you show me how you calculate your income for one kind of plant?

I have 35 papaya plants, before the installation of the irrigation system it was almost impossible to grow papaya plants, because they are consuming a lot of water. But after the installation of the irrigation system there is enough water to grow them now. I am one of the few who can grow papaya in this region. Because of that I have a better position on the market and can get more money.

I also have banana plants and beans for my own use.

I sow watermelons for the first time yesterday on one Manzana of my field. I have around 1650 waterholes with 3 seeds of watermelons in every hole, which are irrigated. But I think only 2 of them will survive. I will get 3300 Watermelon plants. Every plant should give me at least 5 Watermelons. So I will get around 16500 Watermelons this year to sell on the market. I can sell one watermelon for 20C\$ so that I will get around 33000C\$ (1200US\$) this year from watermelons if everything goes well.

Who decides what to plant and what is the decision based on?

I decide by myself what to plant, when to plant and in which amount. I am deciding that on different factors. These are available water, current weather and weather forecasts and also I am following the market to see on which products the demand is high but the offer is low.

Do you have crop failures, if yes why?

Yes, most because of less available water, particularly in the time before the installation of the irrigation system. Also insect pests are a reason for crop failures, but I use insecticide against it.

Did also the quality of the crops increase after the installation of the irrigation system?

Yes, both the quality and the quantity.

What is happening with the profit that you make? And how does it affect your life?

I invest it in my farm to improve the irrigation system and in new Equipment. I also invest to improve my personal quality of life i.e. I bought a television, a gas cooker, a refrigerator. After I bought the refrigerator I started to sell Ice-cream and cooled drinks in my town. And I save a little bit of the money for bad times.

System

What kind of system do you have?

I have a solar based drip irrigation system with a 750 liter water tank. I have 8 solar panels with 100 watts. The pump is from the company "Grundfos".

How did you irrigate your field before the irrigation system?

I had 2-3 workmen and a draft horse pulled water from my well and brought it to the field.

Thank you very much for the Interview!