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Drip irrigation for potatoes in rain fed agriculture - evaluation of drip tape/drip line positions and irrigation control strategies

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Abstract

To produce a stable amount of potatoes of high quality a well distributed water supply matched to the needs of the culture is essential. Although average precipitation in Germany resp. Bavaria delivers enough water to successfully grow most crops suitable to the locale climate, water is often the limiting factor especially for potatoes (and vegetables) on sandy soils and during periods with no or little precipitation. Drip irrigation has worldwide proven to be the most water and energy efficient irrigation method. Therefore it should be the preferred method for future irrigation applications. There is a broad knowledge about drip irrigation for regions with irrigation agriculture. But there is little knowledge about the application of drip irrigation as supplementary irrigation in rain fed agriculture.

The aim of the project was to investigate and evaluate the effects of different drip tape / drip line position and irrigation control strategies for potatoes and to deduce extension recommendations from the results.

To investigate and to evaluate the different drip tape / drip line positions and irrigation control strategies a randomized plot design with four repetitions was created. Due to the factors and their combination up to 12 irrigation circuits became necessary. All circular flows could be controlled via mobile data transfer and micro controllers. Three drip pipe / drip tape positions (on top of the ridge, between every ridge and between every second ridge) and four irrigation control strategies (start of irrigation at 60 % and 80% effective field capacity, irrigation rate of 4 mm^d⁻¹, 6 mm^d⁻¹) have been investigated. Soil moisture was simultaneously determined using weather data and a soil moisture model and by using different sensors. Potato yields and quality were determined after harvest. The experiments have been carried out on 3 resp. 2 locations with different soil types (light and heavy soil).

The gained results show that under German resp. Bavarian conditions drip irrigation significantly increases potato yield and quality especially on sandy soils. On heavy soils positive effects can only be reached in very dry years. On sandy soils only the drip tape /drip line position on top of the ridge is able to continuously produce increased yields without the risk of water leakage. A high frequency of small water applications is also required.

On heavy soils also drip tap / drip line positions between every, or between every second ridge increased the potato yield, although yield effects could only be detected in years with very dry periods.

The differences in yield between different irrigation control strategies have not been significant. Under Bavarian conditions and for potatoes 65 % effective field capacity can be recommended as starting point of irrigation. To avoid water leakage the height of the daily water application and the frequency has to be adapted to soil conditions, the drip tape position, and the distance between the drippers.

The results of the three year investigation were used to develop an internet based optimized irrigation model with an integrated water leakage module.

Keywords: irrigation, drip irrigation, drip line position, potato, control

1 Introduction

To produce a stable amount of potatoes of high quality a well distributed water supply matched to the needs of the culture is essential. Although average precipitation in Germany resp. Bavaria delivers enough water to successfully grow most crops suitable to the locale climate, water is often the limiting factor especially for potatoes (and vegetables) on sandy soils and during periods with no or little precipitation. In Germany resp. Bavaria the frequency of these dry periods during the growing season should increase due to the impacts of climate change.

Drip irrigation has worldwide proven to be the most water and energy efficient irrigation method. Therefore it should be the preferred method for future irrigation applications. There is a broad knowledge about drip irrigation for regions with irrigation agriculture. But there is little knowledge about the application of drip irrigation as supplementary irrigation in rain fed agriculture.

1.1 State of the art

Drip irrigation systems typically consist of three main technical components: The control and filter unit, the distribution pipes and the drip lines with the emitters / drippers. The control unit cleans the water from sand and other material that can block the drippers, reduces the water pressure and controls the volume flow of different irrigation circuits and the injection of fertilizer. The water reaches the drip tapes via the distribution pipes. The positioning of the drip tapes can be either on the soil surface (surface drip irrigation) or below the surface (subsurface drip irrigation). Drip tapes are manufactured from polyethylene with a wall thickness between 0.15 and 1.2 mm. Drippers are integrated every 300 to 800 mm into the drip tapes and emit the irrigation water with a flow rate in the range between 0.5 and 2.5 l h⁻¹. This flow rate results in typical irrigation rates between 1 and 6 mm d⁻¹. Specific dripper constructions are able to compensate pressure differences up to 300 kPa along the drip line length emitting the same amount of water from the first to the last dripper of a field length up to 400 m. Drip irrigation tries to hold the moisture content of the soil nearby the field capacity (Paschold, 2010).

Caused by this direct and exact way of water application losses e.g. by evaporation, leaching, run off or wind drift can be minimized or avoided. This results in very high water use efficiency (Nir, 1982; Dasberg, 1999). Investigations with different cultures have shown, that the yield with drip irrigation is equal or higher with lower water application compared to sprinkler irrigation (Phene et al., 1992; DeTar et al., 1994; DeTar et al., 1996; Neibling and Brooks, 1995; Lamm and Trooien, 2003). Additionally drip irrigation is very energy efficient (Nir, 1982; Dasberg, 1999). This is the result of the low working pressure (typically lower than 200 kPa) and the high water efficiency (less water has to be pumped compared to other irrigation methods) (Batty et al., 1975; Shoji, 1977).

Another advantage of drip irrigation is the fact, that fertilizer can be added to the irrigation water (fertigation). A fertilization adapted to the needs of the plants and in a high frequency becomes possible (Nir, 1982; Dasberg, 1999). The reviewed investigations did not deliver clear results on yield effects of fertigation (Camp, 1998).

As additional advantages of drip irrigation the low work time requirements during irrigation, a reduced risk of pest infestation due to dry leaves and lower weed grows due to partial soil

wetness are mentioned. Furthermore the efficiency and effects of drip irrigation are independent of the daytime of irrigation (evaporation) and the influence of wind (Nir, 1982; Dasberg, 1999). Contrary to these advantages is the higher investment and high work time requirements during laying and collecting of drip tapes.

Based on the mentioned advantages and due to increased water shortage caused by climate change the drip irrigation gains increasing attention within international research activities.

1.2 Aim of the investigations

The aim of the project started in 2009 was to investigate and evaluate the effects of different drip tape / drip line positions and irrigation control strategies as supplementary irrigation for potatoes in rain fed agriculture and to deduce extension recommendations from the results.

2 Materials and methods

To investigate and to evaluate the different drip tape / drip line positions and irrigation control strategies a randomized plot design with four repetitions was developed. All plots have been 3 m in width (four rows with 750 mm row width) and 10 m in length. Only the two center rows have been monitored, evaluated, sampled and harvested. Due to the factors and their combination up to 12 irrigation circuits became necessary. All circular flows could be controlled via mobile data transfer and micro controllers (Figure1).



Figure 1: Left: Control unit for up to 12 irrigation circuits with pressure reducer, filter, magnetic valves, water meters and electronic controller. Middle: Distribution pipes of 7 irrigation circuits with branches for the drip tapes. Right: Drip Tape position on top of the potato ridge.

Three drip pipe / drip tape positions (on top of the ridge, between every ridge and between every second ridge) and four irrigation control strategies (start of irrigation at 60 % and 80% effective field capacity, irrigation rate of 4 mmd^{-1} , 6 mmd^{-1} or 8 mmd^{-1}) have been investigated in the years 2010 – 2012 (Figure 2).



Figure 2: Drip pipe / drip tape positions. Left: on top of the ridge. Middle: between every ridge. Right: reduced between every second ridge.

In 2013 an additional drip tape position every second row between a so called "M-ridge" was integrated into the investigations.

Soil moisture was simultaneously determined using weather data and a soil water resp. soil moisture model and by using different sensors (tensiometer). The model daily balances evapotranspiration, leaching, precipitation and irrigation. Evapotranspiration is determined by the grass-reference-method (Allen et al., 1998) the adaptation of the method to the specific situation in potatoes is realized using specific kc-values (Paschold et al., 2011). Additional and varying correction values have been deduced and evaluated within the project. They account for a specific behavior of soil and soil surface with variable moisture.

Potato yields and quality were determined after harvest and compared to the used irrigation water. The experiments have been carried out on 3 resp. 2 locations with different soil types (loamy sand and silty clay).

The results of the three year investigation were used to develop an internet based optimized irrigation model with an integrated water leakage module. This model and application is currently under evaluation on a number of potato growing farms in Bavaria.

3 Results

From soil physical analysis information about the correlation between volumetric water content and soil moisture tension could be derived. They also delivered soil data important for irrigation control (Table 1).

Table 1: Soil physical properties important for irrigation purposes at the test plot sites in 2010-2012.

location	Abenberg		Thalmassing	
soil	loamy sand		silty clay	
	water content [vol.%]	soil moisture tension [hPa]	water content [vol.%]	soil moisture tension [hPa]
field capacity	16	62	30	62
100% effective field capacity	16	62	30	62
80% effective field capacity	13	260	27	509
65% effective field capacity	11	540	24	1200

There is also a slight difference in climate data between both locations (Table 2).

Table 2: Climate data of the test plot sites in 2010-2012.

location	Abenberg		Thalmassing	
soil	loamy sand		silty clay	
climate	average temperature [° Celsius]	annual precipitation [mm]	average temperature [° Celsius]	annual precipitation [mm]
2010	7.6	668	7.8	708
2011	9.2	626	9.6	737
2012	9.0	565	9.4	710
10-years average	8.7	667	8.5	648

Although the 10 years average of precipitation is lower at Thalmassing (silty clay), in the investigation period 2010-2012 this location had about 10 % more rain than Abenberg (loamy sand).

The analysis of the reaction of potato yields on drip tape / drip tape positions and the above mentioned irrigation strategies is shown in the following tables.

In a first attempt only the reaction on drip tape positions is analyzed while all irrigation strategies are put together.

It becomes clear that the influence of the weather in the specific years and the different soil properties are very dominant and determines the height and level of the difference between the irrigated and the not irrigated variants (Table 2 and 3).

Table 2: Relative potato yields with different drip tape positions on loamy sand in 2010-2012 (absolute potato yields not irrigated = 100% 2010: 47.1 tha⁻¹, 2011: 48.1 tha⁻¹, 2012: 49.9 tha⁻¹).

drip tape position	irrigation strategy	relative potato yield [%]			
		2010	2011	2012	2010-2012
no drip tape	no irrigation	100	100	100	100
on top of every ridge	all strategies	145	115	193	151
between every ridge	all strategies	141	112	---	---
reduced, between every second ridge	all strategies	128	107	197	144

Table 3: Relative potato yields with different drip tape positions on silty clay in 2010-2012 (absolute potato yields not irrigated = 100% 2010: 51.7 tha⁻¹, 2011: 57.9 tha⁻¹, 2012: 84.5 tha⁻¹).

drip tape position	irrigation strategy	relative potato yield [%]			
		2010	2011	2012	2010-2012
no drip tape	no irrigation	100	100	100	100
on top of every ridge	all strategies	132	110	108	117
between every ridge	all strategies	126	105	---	---
reduced, between every second ridge	all strategies	127	102	106	112

Significant effects of drip irrigation on the potato yields, compared to not irrigated crops, could be registered on loamy sand in all three years, on silty clay only in one of three years. Also the level of potato yield difference between irrigated and not irrigated crops clearly differentiate between both soils. On silty loam the highest difference registered in 2010 was 32 %, in average over the three years it was 17 % (both with drip tapes on top of the ridge), while the highest difference on loamy sand was over 90 % with an average of 51 % over 3 years. While the different drip tape positions did not clearly differentiate in yield on silty loam, the position on top of the ridge performed better on loamy sand in two of three years.

Due to small adaptations and modifications of the irrigation strategies between the locations and the years it is not possible to analyze the data together and show them in one table. Therefore table 4 shows the reaction of potato yield to different drip tape positions and irrigations strategies at the location Thalmassing (silty clay) in the year 2010.

Table 4: Relative potato yields with different drip tape positions and irrigation strategies on silty clay in 2010 (absolute potato yield not irrigated 100% 2010: 51.7 tha⁻¹).

drip tape position	irrigation strategy starting point, amount, frequency	relative potato yield [%]	
		single	average
no drip tape	no irrigation	100	100
on top of every ridge	< 60% eff. field capacity, 8 mmd ⁻¹	133	132
on top of every ridge	< 80% eff. field capacity, 4 mmd ⁻¹	130	
on top of every ridge	after flowering and < 80% eff. field capacity, 8 mmd ⁻¹	133	
between every ridge	< 60% eff. field capacity, 8 mmd ⁻¹	121	124
between every ridge	< 80% eff. field capacity, 4 mmd ⁻¹	125	
between every ridge	after flowering and < 80% eff. field capacity, 8 mmd ⁻¹	127	
between every second ridge	< 60% eff. field capacity, 8 mmd ⁻¹	123	126
between every second ridge	< 80% eff. field capacity, 4 mmd ⁻¹	125	
between every second ridge	after flowering and < 80% eff. field capacity, 8 mmd ⁻¹	130	

Irrigation strategies, defined by the starting point of irrigation, the frequency and the amount of irrigation water applied during every irrigation period did not differentiate significantly in this example.

As long as the starting point of irrigation was not lower than 65 % of effective field capacity the behavior of the different irrigation strategies did also not differentiate in the other years and at the other location.

In 2013 in Abenberg (loamy sand) the drip tape position on every second M-ridge was introduced (Figure 3) and the irrigation strategy was modified two a two steps approach where the irrigation rate is increased when the soil moisture decreases during irrigation under the level of 50% effective field capacity (Table 5).



Figure 3: Drip pipe / drip tape positions. Left: reduced between every second ridge. Right: reduced between every second ridge of a M-Ridge.

Table 5: Relative potato yields with different drip tape positions and irrigation strategies on loamy sand in 2013 (absolute potato yield not irrigated 100% 2010: 23.4 tha^{-1}).

drip tape position	irrigation strategy starting point, amount, frequency	relative potato yield [%]	
		single	average
no drip tape	no irrigation	100	100
on top of every ridge	< 70% eff. field capacity, 4 mm2d^{-1}	128	182
on top of every ridge	< 70% eff. field capacity, 4 mm2d^{-1} and < 50% eff. field capacity, 8 mm2d^{-1}	196	
on top of every ridge	< 70% eff. field capacity, 4 mm2d^{-1} and < 50% eff. field capacity, 12 mm2d^{-1}	221	
M-ridge between every second ridge	< 70% eff. field capacity, 2 mmd^{-1}	177	209
M-ridge between every second ridge	< 70% eff. field capacity, 2 mmd^{-1} and < 50% eff. field capacity, 4 mmd^{-1}	196	
M-ridge between every second ridge	< 70% eff. field capacity, 2 mmd^{-1} and < 50% eff. field capacity, 6 mmd^{-1}	253	

Due to the fact that the M-ridge configuration has only the have number of emitters, the irrigation frequency was increased (doubled) at the amount of water applied at every irrigation period was reduced (50%) to avoid leaching. This two steps approach showed high yield effects in this first year of evaluation.

4 Discussions

Drip irrigation is a water and energy saving irrigation system, but combined with high investment and requires a lot of work for installing and recovering. Therefore it is necessary to use drip irrigation systems as efficient as possible. Due to the fact that drip irrigation does not apply irrigation water to the whole soil surface but to spots or zones beneath the drippers or emitters, the height of irrigation water applications have to be matched with the actual field capacity depending on the soil type and the efficient field capacity.

The possibility of the use of reduced number of drip tapes e.g. between every second potato ridge is limited to soils with higher clay content. In sandy soils and drip tape position between the ridges the irrigation water does not reach the whole ridge, the top area of the ridge dries and warms very fast.

For high yields and high qualities it is necessary to assure a continuous and stress free growing of the tubers during the main growing season. Therefore the core of the potato ridge should be continuously kept cool and damp. Typical procedures used for sprinkler irrigation (starting of irrigation if soil water content drops below 35 – 55 % of the effective water field capacity, Fricke 2009) are not suitable for drip irrigation.

Using an already installed drip irrigation system is no big work. Therefore an early start of the irrigation at a soil water content going below 80 % of the effective water field capacity and a distribution of the irrigation water on a high number of small applications every day or every second day is recommended.

In the moment there are very little and not well working machines available to lay and to recover drip tapes from potato fields. Farmers often work with self-made constructions adapted specifically to their individual situation. Especially during recovering the drip tapes are often damaged and coiled with strongly varying tension causing problems when decoiling. Therefore adapted technology to exactly position and lay drip tapes of different quality also containing connectors on or between potato ridges as well as to recovery them without damaging and to coil them for storage and laying again. The second aim of the mechanization must be the reduction of labor time requirement for laying and recovering drip tapes.

5 Conclusions

- The gained results show that under German resp. Bavarian conditions drip irrigation significantly increases potato yield and quality especially on sandy soils. On heavy soils positive effects can only be reached in very dry years.
- On sandy soils only the drip tape /drip line position on top of the ridge is able to continuously produce increased yields without the risk of water leakage. A high frequency of small water applications is also required to prevent water leakage.
- On heavy soils also drip tape / drip line positions between every, or between every second ridge increased the potato yield, although significant yield effects could only be detected in years with very dry periods.
- The position of the drip tape in the heart of a so called “M-ridge” every second row evaluated for the first time in 2013 seems to have similar yield effects than on top of every ridge. The evaluation of this drip tape position is continued in 2014.
- The differences in yield between different irrigation control strategies have not been significant. Under Bavarian conditions and for potatoes 65 % effective field capacity can be recommended as starting point of irrigation. To avoid water leakage the height of the daily water application and the frequency has to be adapted to soil conditions, the drip tape position, and the distance between the drippers.
- There are very little and not well working machines available to lay and to recover drip tapes from potato fields. Therefore adapted technology to exactly position and lay drip tapes of different quality also containing connectors on or between potato ridges as well as to recovery them without damaging and to coil them for storage and laying again.
- An additional result of the investigation was the development of an internet based optimized irrigation model with an integrated water leakage module to efficiently prevent irrigation water leakage. This model and application is currently under evaluation on a number of potato growing farms in Bavaria

6 Acknowledgements

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