Response of potato to drip and gun irrigation systems

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Abstract: The objective of this study was to evaluate effects of different irrigation and N fertilization regimes by gun irrigation and drip-fertigation on potato production, and subsequently optimize the supply of water and N fertilizer to the growth condition of the specific season and minimize nitrate leaching without compromising profits. Four replicate plots of each treatment with varying predefined and model-based (Daisy and Aquacrop crop model) irrigation and N fertilization levels were used in the study. Two experiments were conducted. In experiment-I, treatments consisted of one drip-fertigation system (DFdsNds) and two gun irrigation systems (GIdsN120 and GIaN120) to display the differences on growth, yield and water use efficiency of potato. All treatments were irrigated according to model simulated soil water content. For fertilization all treatments received a basic dressing at planting of P, K, Mg and micronutrients, and in addition 120 kg N/ha in the gun irrigated treatments and 36 kg N/ha in the drip-fertigated. For the latter, portion of 20 kg N/ha was applied whenever plant N concentration approached a critical value as simulated by the Daisy model. As a result differences in soil water deficit and nitrogen application rates emerged during the season. Soil water content in the drip-fertigation system was higher than gun irrigation systems most time during growth season, with less N used in total (100 kg N/ha) in DFdsNds. GIaN120 used 20 mm less water than the GIdsN120 treatment. Yield was not significantly different between treatments. As a consequence GIaN120 had higher irrigation water use efficiency than GIdsN120 and DFdsNds: 23 and 18%, respectively.

In experiment-II, 14 treatments with different combinations of irrigation and N levels was conducted, all using the fertigation system, among which several treatments were irrigated and/or fertilized with assistance of the Daisy model. Results showed that, soil water content was well simulated by the Daisy model (low root mean square error (RMSE)), whereas the Aquacrop model had higher RMSE, suggesting a requirement of calibration to entail a better performance of Aquacrop model. Increasing N supply showed expected effect on fresh yield, treatments applied with 60, 100, 140 and 180kgN/ha increased fresh yield by 77%, 83%, 90% and 106% compared to treatment without N application. N-fertigation based on Daisy (I1Nds) got higher fresh yield than I1N2, I1Norg and I1Nt by 2%, 4% and 14%, respectively, even all received 100kg N/ha. Hence some effect of N fertilization timing was found, i.e. varying time of the last fertigation. The results indicated giving N too early or late may result in decline of fresh yield. In contrast, increasing irrigation in 140 kg N/ha treatments decreased yield by 4%. In addition, treatments guided with Daisy or Aquacrop had higher irrigation water use efficiency, suggesting that the use of models to guide application allowed a better use of water and N fertilizer in potato production.

Keywords: gun irrigation, fertigation, potato yield, crop growth model, Denmark

Citation: Zhou, Z. J., M. N. Andersen, F. Plauborg, and O. Edlefsen. 2015. Agric Eng Int: CIGR Journal, Special issue 2015: 18th World Congress of CIGR: 1-9.

1 Introduction

Gun Irrigation (GI) system has been commonly used in potato production in Denmark, as it is quite convenient for supplementary irrigation in a climate where the irrigation need may vary from 0 to more than 200 mm during the summer season. However, the system is regarded susceptible to wind and evaporation losses (Kendy et al., 2006; Bavi et al., 2009), often in the range of 10%-20% (Aslyng, 1978). Besides, GI can also result in a non-uniform soil wetting pattern across the hilly potato field (Starr et al., 2005), as water tend to run down the hills. With most proportion of applied water allocated at furrows where less than 15% root distribute (Lesczynski and Tanner 1976), water is in high risk of

Received date: 2014-12-1 **Accepted date:** 2014-12-19

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percolation and rarely beneficial for potato growth. Furthermore, farmers tend to apply all the N at planting, which highly increase the potential of nitrate leaching below root zone. These factors, coupled with a shallow root depth of potatoes grown on coarse textured soil in Denmark (Andersen et al., 1992), often resulted in low yield as well as water and N use efficiency.

Drip-fertigation (DF), by contrast, applies water and fertilizer directly to the base of the plant, with minimal evaporation loss by only wetting a limited area of soil. Potatoes are sensitive to mild water stress due to characteristics of shallow root and relatively low root density, (Lynch et al., 1995; Wright and Stark, 1990), but still it is demonstrated that, by drip irrigation, potatoes could tolerate drought to a certain extent without compromising yield (Kang et al., 2004). This was probably due to favorable condition provided by drip irrigation, which ensures constant and adequate water moisture (Yuan et al., 2003). DF has another advantage of improving distribution of N in the root zone for plant uptake as reported by Li et al. (2004). With high water and N use efficiency (Patel and Rajput, 2007; Phene et al., 1994), DF usually resulted in greater yield response to irrigationthan GI (Beyaert, et al., 2007; Waddell et al., 1999; Abd El-Wahed and Ali, 2013). In addition, farmers prefer to apply all N at planting in the conventional way of potato production in Denmark. However, as high uncertainty exist with respect to mineralization, climate condition and nitrate leaching (Blackmer and White, 1998), this means the actual N demand is difficult to predict. Monitoring nitrogen status and supplementing N (split application) is necessary if one wants to get temporal precision in nitrogen application (Rodrigues et al., 2005). With respect to this, the Daisy simulation model (Hansen et al., 1991) could be a promising N fertilization decision support tool for simulating N status. This would allow growers to simulate N status at any moment and adjust N fertilization according to the need during the particular season taking into account also crop growth. Up until now, comparison of Daisy based dynamic fertilization and conventional fertilization using DF and GI were rarely reported in literature.

In addition, given the fact that intensive and abundant precipitation events occur especially in southern area of Denmark, it is rational to apply nitrogen in discrete doses at different time based on monitoring with remote sensor or simulation model. In our study, we assess the effects of split nitrogen fertilization in terms of yield under different irrigation amounts. These effects are subsequently compared with control treatments (traditional potato growing with static N application).

Hence, specific objectives were to: (1) compare potato response to DF and GI system; (2) determine the effect of irrigation and N fertilization on yield and DM production of potatoes; (3) validate the Daisy and Aquacrop model with measured data.

2 Materials and methods

2.1 Site description and management

Two field experiments with potatoes (Solanum tuberosum L. cv. Folva) were conducted at AU-Jyndevad research station (54^{o}53'60", 9^{o}07'30") in South Jutland, Denmark during summer 2013. The soil is characterized as coarse-textured and contains ca. 76% coarse sand (0.2-2.0 mm), 15% fine sand (0.02-0.2 mm), 4% silt (0.002-0.02 mm) and 3% clay (<0.002 mm). In the top layer (0-20 cm) the organic matter content is about 3% (Hansen, 1976). The plant available water capacity is about 67 mm in the root-zone, which usually reaches to no more than 60 cm depth. The dry bulk density is about 1.55 g/cm^3 for both the plough layer and the subsoil (Hansen et al., 1986).

Meteorological data were taken at a meteorological station 100 m away from the experimental field. The total precipitation from emergence to harvest was 169 mm, the mean temperature at 2 m height and global radiation from sowing to harvest was 15.5˚C and 16.7 MJ/m^2/d, respectively.

Mother tubers were planted in rows 0.75 m apart and at 0.27m distance within the row on 15th May and emerged on 7th June. The field had a previous crop husbandry of winter wheat, potatoes, winter rye, maize, spring barley from 2008 to 2012.

2.2 Experiment design

The first experiment (Exp I) consisted of three treatments: $DF_{ds}N_{ds}$, $GI_{ds}N_{120}$ and GI_aN_{120}, as shown in Table 1.

Table1 Summary of irrigation and fertilization regimes in Exp I

Treatment	Irrigation Criteria	Irrigation frequency	Fertilization Criteria	Dressing time
$GI_{ds}N_{120}$	25 mm deficit Daisy modelled	Whenever water deficit equals 25 mm incl. forecast	120 kg/N/ha 30 kg/P/ha 180 kg/K/ha	Planting
GI_aN_{120}	25 mm deficit Aquacrop modelled			Planting
$DF_{ds}N_{ds}$	90% θ_f –SWC_t[a]	Every two days	30% of calculated N demand 30 kg/P/ha 180 kg/K/ha 70% of calculated N demand	When critical N level was reached based on Daisy and applied in 10 kg/N/ha portions

Note: a: θ_f denotes field capacity and SWC_t represents actual soil water content (mm)

The experiment was a randomized complete block design with each treatment replicated four times.

The gross area of each plot was 6.0 m wide and10.3 m long, to avoid edge effect between adjacent plots, net areas of 3.0 m×6.5 m were reserved in each plot for final harvest.

The second experiment (Exp II) consisted of varying amount and timing of irrigation and fertilization:

I_0: No irrigation, I_1: drip irrigation was implemented every two days to replenish soil water deficit up to 90% of FC as measured by TDR (see below). I_d: received 80 % of the amount of water in I_1 and 60% of I_1 at the tuber initiation stage and from tuber bulking to harvest, respectively, which corresponded to the periods 27th June to 25th July and 25th July to harvest,. I_a and I_{ds}: Irrigation was scheduled by using the Aquacrop and Daisy model, respectively.

I_1 treatment was subjected to five static N application rates: 0 kg/N/ha (N_0), 60 kg/N/ha (N_1), 100 kg/N/ha (N_2), 140 kg/N/ha (N_3), 180 kg/N/ha (N_4), and two dynamic N fertilization mode N_{ds} and N_t, defined as fertilization regimes following Daisy model and N-tester devices, respectively. In addition, I_1N_{org} used pig slurry as basic dressing and afterwards followed N-tester. I_d treatment was subjected to two N application levels: N_3 and N_{ds}. I_a and I_{ds} were subjected to only one N application regime N_3 and I_{d1}, respectively. Furthermore, three control treatments, namely I_0-N_0, I_0-N_3 and I_1-N_0were implemented. It produced 14 treatments in all with four replicates for each treatment arranged in a randomized complete block design with gross plot size of 12.0 m × 8.1 m, and the net area for harvest at maturity was 3.0 m × 6.0 m.

In Exp II, 30 kg/P/ha, 180 kg/K/ha and 42 kg/N/ha were applied as granular fertilizers in all treatments at sowing except for N_0, while I_0N_3 received 140 kg/N/ha, the remaining N was added via fertigation from 49 days after planting (DAP) with the same rate ca. 20 kg/N/ha. The slurry was analyzed for dry matter content, total N (Kjeldahl-method), ammonium-N, P and K, which were 1.05%, 2.2 kg/t, 2.07 kg/t, 0.14 kg/t and 1.53 kg/t, respectively. Pig slurry was placed 10 cm under the soil surface with harrow tines (25 cm between the tines) shortly before preparation of furrow for the mother tubers. The schematic fertilization timing and rate were as Table 2:

Table 2 Summary of irrigation and fertilization regimes

Treatment	Irrigation amount, mm	Time of fertilization (DAP) and N rate (kg N/ha)								Total fertilization (kgN/ha)
		1	49	53	56	63	70	77	84	
ExpI										
$DF_{ds}N_{ds}$	110	36	24	20	0	0	20	0	0	100
$GI_{ds}N_{120}$	111	120	0	0	0	0	0	0	0	120
GI_aN_{120}	90	120	0	0	0	0	0	0	0	120
Exp II										
I_dN_3	94	42	18	20	20	20	20	0	0	140
I_dN_{ds}	86	42	18	20	0	0	20	0	0	100
I_1N_0	126	0	0	0	0	0	0	0	0	0
I_1N_1	141	42	18	0	0	0	0	0	0	60
I_1N_2	184	42	18	20	20	0	0	0	0	100
I_1N_3	121	42	18	20	20	20	20	0	0	140
I_1N_4	122	42	18	20	20	20	20	20	20	180
I_1N_{ds}	111	42	18	20	0	0	20	0	0	100
I_1N_t	111	42	18	20	0	0	0	20	0	100
I_1N_{org}	122	42	18	20	0	0	0	20	0	100
I_aN_3	100	42	18	20	20	20	20	0	0	140
$I_{ds}N_{ds}$	113	42	18	20	0	0	20	0	0	100

Note: The split fertilization for dynamic treatments were conducted according to modelling results

2.3 Management and data collection

The furrow for planting the mother tubers was about 8 cm below field level. Mother tubers were ridged with 15 cm soil. Drip lines with distance between emitters of 20 cm, delivering 1 L/h, drip lines were buried 3 cm below the top of the ridge during ridging. Pesticides and fungicides were sprayed according to local experience.

Canopy reflectance in each plot was measured weekly from 30 to 89 DAP using Rapidscan CS-45 canopy reflectance instrument (Holland Scientific, Lincoln, Nebraska). The sensor simultaneously measured crop/soil reflectance at 670 nm, 730 nm and 780 nm band. Ratio vegetation index (RVI) was derived from measurements of spectral reflectance in two bands at 780 and 670 nm.

Soil water content was measured by TDR, 3 pairs of probes (77cm, 60cm and 43cm length) were placed vertically for soil water content measurement. They were installed at the top of ridge, the midway from ridge to furrow, and at the furrow, respectively. Measurement was done three to four times per week until harvest.

Crop growth, nitrogen uptake and soil water balance was simulated by Daisy and Aquacrop model every other day to guide the irrigation and fertiagtion.

To investigate crop performance with different N rates and watering regimes, six plants from two adjacent rows in each plot were sampled at 48, 58, 65, 78 and 90 DAP. Above and below ground parts were separated and above ground parts were subsequently divided into leaves and stems, the top was defined as 3 cm above the seed tuber without roots and stolon. Fresh and dry weight were examined, DM was determined by drying samples of the plants for 24 h at 80 ℃.

Defoliation was done separately for each treatment from 94 to 112 DAP according to tuber size distribution. Potato tubers were harvested mechanically three weeks after defoliation. Fresh yield and DM were recorded.

2.4 Statistical analysis

Data were subjected to analysis of variance (ANOVA) to assess the effects of treatments on fresh yield, tuber DM and IWUE of potato using SAS. ANOVA analysis was conducted at 5% probability level.

3 Results

3.1 Yield and irrigation water use efficiency (IWUE)

In Exp I, with less N application in total, drip fertigation resulted in slightly higher fresh yield ($DF_{ds}N_{ds}$) than both gun-irrigated treatments ($GI_{ds}N_{120}$ and GI_aN_{120}). Also, tuber DM and IWUE did not differ significantly in response to irrigation system; $GI_{ds}N_{120}$ obtained the highest tuber DM, even though other findings showed that excessive supply of N could delay transfer of dry matter to tubers (Haverkort et al., 2000). In Exp II, It is noteworthy that I_1N_1 and I_1N_2 received very high irrigation (Table 2) compared to other I_1 treatments. The explanation was probably soil variation where TDR probes were installed or failure of the connections of the TDR system for these probes, leading to underestimation of water content and subsequent irrigation. Fresh yield did not demonstrate significant difference in relation to varying N rates with exception of I_1N_0. This is consistent with Darwish et al. (2006) study where yield showed marginal response to N rates. The greatest difference in fresh yield was between I_1N_4 (46 t/ha) and I_1N_0 (22 t/ha), compared to fresh yield of I_1N_0, applying N enhanced yield by 77%, 83%, 90% and 110% for I_1N_1, I_1N_2, I_1N_3, and I_1N_4, respectively. Interestingly, even though all received 100 kg/N/ha, but differed in time of the second/last fertigaion. I_1N_{ds} obtained higher yield (42 t/ha) than I_1N_2, I_1N_{org} and I_1N_t. This may indicate that supplemental N given too early or too late tended to lead to decline of fresh yield. DM also showed the same trend as fresh yield in treatments receiving 100 kg N/ha. In general, DM did not present a link with N levels in I_1 treatments with the exception of I_1N_0, which obtained significantly low tuber DM (4.3 t/ha). I_1N_4 and I_1N_{ds} obtained highest IWUE (377 kg/ha/mm), significantly higher than I_1N_0 and I_1N_2 by 112% and 68%, respectively, results indicated increasing N levels or applying N according to Daisy considerably enhanced IWUE. In I_1 treatments receiving 100 kg N/ha, I_1N_2 showed significantly lower IWUE due to the extremely high amount of irrigation it received.

Fresh tuber production did not present a consistent relation with irrigation levels. I_dN_3 obtained higher yield than I_1N_3, and both of them got higher yield than I_aN_3. I_1N_{ds} got higher yield than I_dN_{ds}, both of them got higher yield than $I_{ds}N_{ds}$. I_1N_{ds} and I_dN_{ds} obtained high DM than $I_{ds}N_{ds}$, among N_3 treatments, full irrigation lead to the highest DM in I_1N_3, higher than I_aN_3. With less water used and a comparable fresh yield, I_dN_3 and I_dN_{ds} treatments obtained the highest IWUE, 471 and 446 kg/ha/mm, respectively. (See Table 3)

Table 3 Summary of yield and tuber DM results from final harvest

Treatment	Yield, t/ha	Tuber DM, t/ha	IWUE, kg/ha/mm
ExpI			
$GI_{ds}N_{120}$	46 a	10.5a	418a
$DF_{ds}N_{ds}$	48 a	9.9a	434a
GI_aN_{120}	46 a	9.7a	514a
Exp II			
I_0N_0	15 c	3.0e	
I_0N_3	27 bc	6.0cd	
I_dN_3	44 a	9.0abc	471a
I_dN_{ds}	38 ab	8.1abc	446a
I_1N_0	22 c	4.3de	178d
I_1N_1	40 ab	9.0abc	281bcd
I_1N_2	41 a	8.5abc	224cd
I_1N_3	42 a	9.7ab	351ab
I_1N_4	46 a	9.3ab	377ab
I_1N_{org}	37 ab	8.2abc	300bc
I_1N_{ds}	42 a	8.8abc	377ab
I_1N_t	40 ab	8.5abc	366ab
$I_{ds}N_{ds}$	35 ab	7.3bc	312bc
I_aN_3	40 ab	8.2abc	404ab

Note: Values within a single column followed by the same letter are not significantly different (Tukey test at the level of 0.05).

3.2 Soil water content (SWC)

The measured soil water content for the soil profile to 0.6 m depth is the weighted mean value of measurements with TDR at different depths. SWC was more stable and generally higher in $DF_{ds}N_{ds}$ than in $GI_{ds}N_{120}$. SWC increased at 58, 61, 72 and 84 DAP in $GI_{ds}N_{120}$ due to irrigation. SWC between 60 DAP and 70 DAP were generally lower than other periods, because this period coincided with vigorous growth stage which depleted more soil water. In addition, a severe drought occurred in this period. In contrast, SWC before 50 DAP and after 80 DAP was above FC due to frequent precipitation plus low water consumption by evapotranspiration. Average SWC in $DF_{ds}N_{ds}$ and $GI_{ds}N_{120}$ were 66 and 64 mm, respectively.

Volumetric water content (%) in the center portion of the potato hill, which was represented and measured by the 77 cm probe installed in the center of hill, were 10.7%, 7.9% and 9.5% in $DF_{ds}N_{ds}$, $GI_{ds}N_{120}$ and GI_aN_{120}, respectively. This agrees with other finding, which showed that SWC were greater under drip irrigation than sprinkler irrigation by an average of 32% (Eric et al., 2007). (See Figure 1)

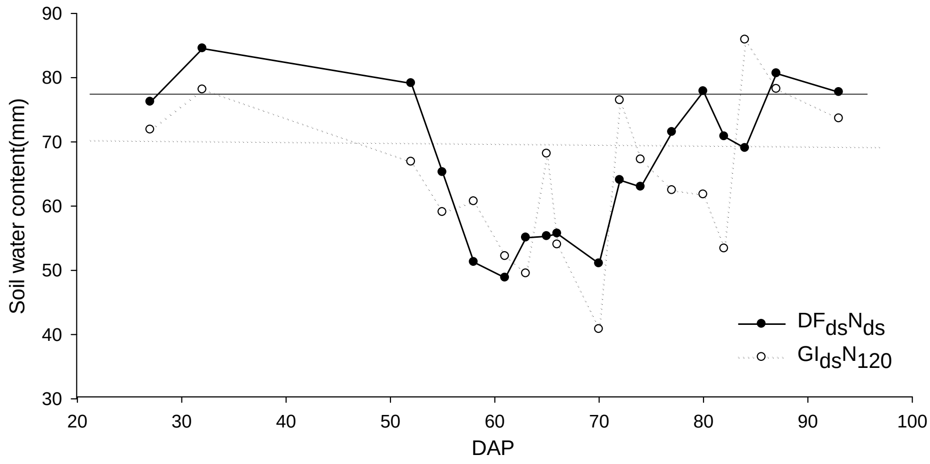

Figure 1 Soil water content change with time for $DF_{ds}N_{ds}$ and $GI_{ds}N_{120}$ in Exp I. The horizontal solid and dotted line represent field capacity (FC) of $DF_{ds}N_{ds}$ and $GI_{ds}N_{120}$, which were 77 and 72 mm in the top 600 mm soil profile, respectively.

3.3 Daisy and Aquacrop simulation of SWC in $I_{ds}N_{ds}$ in ExpII

There are Equation 1 and Equation 2:

$$RMSE_{Daisy}=\sqrt{\sum_1^n \frac{(P-O)^2}{n}}=6.5 \quad (1)$$

$$RMSE_{Aquacrop}=\sqrt{\sum_1^n \frac{(P-O)^2}{n}}=13.3 \quad (2)$$

Where n represents total number of observations, O and P are observed and predicted values.

Soil water content was well simulated by the Daisy model (low root mean square error (RMSE)), whereas the Aquacrop model had higher RMSE, suggesting a requirement of calibration to entail a better performance of Aquacrop model. (See Figure 2)

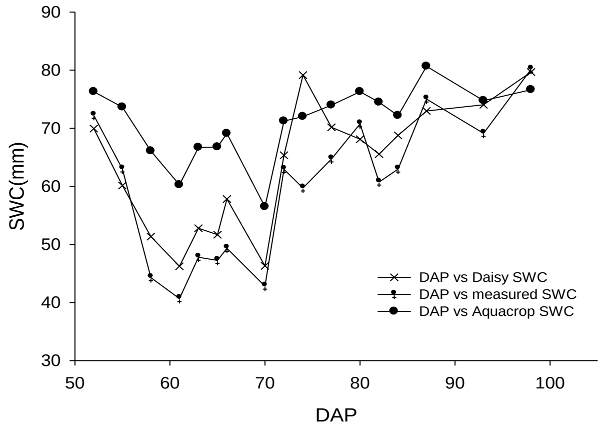

Figure 2. SWC change with time during the growing season, SWC was compared between TDR measured value and predicted values of Daisy and Aquacrop model.

4 Discussion

Drip-fertigation did not result in considerable less water supply compared to gun irrigation system (Table 2) even grown with a severe drought season. Two points may explain this. On one hand, drip-fertigated potatoes were irrigated more frequently than in the gun irrigation system, which may have caused slightly higher transpiration than for the gun irrigation system. On the other hand, due to abundant rainfall in June the canopy have been fully developed in both systems (data not shown) by the time of first fertigation, therefore the evaporation loss from bare soil did not differ from that in gun irrigation.

Fresh yield of $DF_{ds}N_{ds}$ was only marginally higher than $GI_{ds}N_{120}$. Yield in drip-fertigation system could have been further enhanced relative to gun irrigation (Waddell et al., 1999). In this study, this might have been achieved by applying fertilizer earlier, thereby provided adequate N for early canopy growth. DM in $GI_{ds}N_{120}$ were higher than that in $DF_{ds}N_{ds}$, the causes of the slightly decrease of DM in $DF_{ds}N_{ds}$ could be explained by the fact that the initial N supply was inadequate (36 kg N/ha) for maximum canopy growth until the first fertigation was done. Furthermore, it took some time to produce more leaves after supplementary N addition meaning that DM loss was inevitable. As such, the best strategy was that N application at planting should be sufficient for early canopy growth and supplementary fertigation should be in time to avoid N deficiency.

In this study, fresh yield and IWUE increased with increasing N rate. For treatments I_1N_{org}, I_1N_{ds}, I_1N_t and $I_1N_{2,}$ which received 100 kg/N/ha, I_1N_{ds} obtained the highest DM. The difference was probably caused by fertigation time. For instance, the last fertigation time in I_1N_t and $I_1N_{org,}$ was conducted in 77 Dap. It corresponded to 53 days after emergence and was close to maturation stage. Considering that the maximum removal of nutrients occurs before the 60th day after emergence (Kolbe and Stephan-Beckmann, 1997), so, little nitrogen would be taken up in I_1N_t and I_1N_{org} after the last fertigation. This decreased the leaf growth and DM production as a sequence. Even though the significant difference was not found between 100 kg N/ha treatments, it is noteworthy that I_1N_{Org} got the lowest DM. This can be explained in terms of the slow release of mineral N from organic matter applied.

Jensen et al. (2010) found that deficit irrigation (70% of FI) after tuber initiation would cause significant yield loss for potatoes. In this study, significant difference was not found between different irrigation levels, probably because the time of the irrigation treatment was close to the end of tuber initiation. Furthermore, water was given at a high frequency with drip irrigation and comparable high soil water content was maintained during the growing season (measured SWC data not shown). The SWC difference between varying irrigation levels in N_3 and N_{ds} was confined to a fairly narrow range except for $I_{ds}N_{ds}$, which consistently had the lowest SWC.

5 Conclusions

With similar irrigation amount and 20 kg N/ha less N, $DF_{ds}N_{ds}$ had slightly higher yield and IWUE than $GI_{ds}N_{120}$.

Among I_1 treatments, fresh yield and IWUE increased with increasing N rate. For treatments I_1N_{org}, I_1N_{ds}, I_1N_t and $I_1N_{2,}$ which received 100 kg N/ha, I_1N_{ds} obtained the highest TDM. I_1N_{Org} demonstrated the lowest TDM production.

Daisy gave a good simulation of SWC in the $I_{ds}N_{ds}$ treatment.

Acknowledgments

We thank all technicians in Jyndevad research station, Denmark for excellent technical support during the experiment. Thank is also given to CSC in China for the financial support of Zhenjiang Zhou for his Ph.D research. Fund of this study was supported by the EU project (Figaro 925729).

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