Evaluation of regulated deficit irrigation on the yield of Potato at Adet

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Abstract

Regulated deficit irrigation (RDI) aims to optimize water use efficiency and the crop yield from a unit of water applied. In this study, three deficit irrigation water levels (20%, 40% and 60%) were applied at different potato growth stages independently namely: i) initial stage which includes the time from sowing to 10% ground cover, ii) crop development stage which is from 10% to 70% ground cover, iii) mid-season stage including flowering and yield formation, and iv) late season stage including rippening and harvest. The objective of this study was to improve water productivity with application of deficit irrigation so as to enhance crop production and save water for various uses. Field work was conducted at Adet Agricultural Research Centre for two years (2009 and 2010). The experiment was laid down in a randomized complete block design with three replications. Irrigation water was applied using furrow irrigation method. Data collected from Field experiment was analysed using SAS statistical software. The results of the combined analysis of the two year data showed that deficit irrigation did not significantly affect most biological parameters. Despite this, 60% deficit irrigation (375 mm net irrigation) at crop development stage (day 25 to day 55) gave highest marketable yield (16 ton ha^{-1}) and total yield (21ton ha^{-1}) and dry matter content (22%) which is within the acceptable industrial standard (20-25%). Moreover, results of the experiments revealed that 51 mm (510 m^3 ha^{-1}) of irrigation water, which is about 12% of the total net irrigation, could be safely saved without significant potato yield loss at Adet.

Keywords: Deficit, furrow, irrigation, potato.

Introduction

Efficient use of irrigation water enhances production and thus the income of the people and the country as well. Frequent occurrence of drought requires a proactive and rational water management approach, which could be helpful to both managers and farmers. Related to water restriction, a recent study shows that a decrease of 10% in water supply would result a reduction of about 2% net agricultural product (El Amam, 2001). Under high and very

high demand conditions, the gross margin per unit of water applied decreases for the potato and the tomato crops but increases for the wheat crop. So, considering an average year, the adoption of a deficit irrigation scheme is feasible for the potato and tomato crops, while for the wheat crop it is not economically advantageous to use deficit irrigation, this is the reason why the crop is usually grown in rain fed conditions (El Amam, 2001).

In times when irrigation water is limiting, the farmer may not have enough water to irrigate all the crop fields. In this case, the farmer may decide to spread the available water over a large area, although it is less than the optimal amount. Here, it is good to know i) the crops which suffer most from water shortage and ii) the growth stages during which the various crops suffer most from water shortage (Awulachew *et al.*, 2009). If various crops are grown on a given field, it is advisable to give priority to irrigate the most drought sensitive crops.

The total growing season of a given crop is usually divided into four stages. These are i) initial stage which includes the time from sowing to 10% ground cover; ii) crop development stage which is from 10% to 70% ground cover; iii) mid-season stage including flowering and grain setting or yield formation; and iv) late season stage including rippening and harvest. In general, it is stated that out of the four growth stages, the mid season stage is the most sensitive to water shortages. This is mainly because it is the period of the highest crop water needs. Hence, if water shortage occurs during this stage, the negative effect on yield will be pronounced.

To see the effect of limited water application on yield and production, consideration must be given to the effect of the limited water application during the individual growth periods of the crops (FAO, 1979). If crops under consideration are less sensitive to water deficit and can be grown with acceptable yields but without meeting full water requirements, scheduling of supply is based on minimizing water deficits in most sensitive growth periods. During periods of unpredictable water shortages, within season adjustment of water scheduling must be made in relation to the difference in yield response to water deficits on the crops and their individual growth periods. In terms of water management this means water allocation of limited supply should be directed towards meeting full water

requirements of these sensitive stages rather than spreading the available limited supply to the crop equally over the total growing period.

Maintaining a reduced soil moisture deficit keeps vegetative growth under control while photosynthesis remains unaltered. A reduced moisture deficit therefore has been stated as the most agronomic desirable soil moisture level. Excessive water stress should be avoided, as it reduces photosynthetic activity which will affect both vegetative and reproductive growth. Regulated deficit irrigation (RDI) may be implemented during part of the growing season by regulating moisture within a desired deficit range. RDI aims to optimize water use efficiency and therefore the yield returned per unit of water applied. Any minor yield loss which may result from the implementation of a mild moisture deficit/stress under RDI is compensated by the benefits of saved water to irrigate additional areas. The most desirable benefits associated with implementing a RDI strategy are: i) the reduction in excessive vegetative growth; ii) maintenance of soil moisture in the most agronomic desirable range; and iii) an increase in water use efficiency (FAO, 2002). The objective of this study was, therefore, to improve water productivity with application of deficit irrigation so as to enhance crop production and save water for various uses.

Materials and methods

The experiment was conducted at Adet research station 43 km from Bahir Dar during 2009 and 2010. Adet is located at 11^0 17' N latitude and 37^0 43' longitude at an altitude of 2240 m above mean sea level. The mean daily maximum temperature ranges from 22.5^0C (July and August) to 29.4 ^{0}C (March) and the mean daily minimum temperature ranges from 5.4 ^{0}C (January) to 12.1 0C in August. The soil is characterized by pH of about 5.41, organic matter content of 2.2%, bulk density of about 1.39 and its texture is basically clay.

To calculate the irrigation water requirement of potato for Adet metrological and other necessary data were collected from the National Meteorological Agency and other reliable sources. Potential evapotranspiration of the area was calculated for the recent ten years and the resulting value was fitted to 80% probable value (Table 1).

Table 1. Potential evapo-transpiration values (mm day^{-1}) for Adet research station.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1996	3.62	4.52	4.69	4.67	3.9	3.73	3.24	3.05	3.67	4.03	3.42	3.42
1997	3.62	4.39	4.51	4.80	4.35	3.60	3.16	3.30	3.97	3.62	3.51	3.57
1998	3.86	4.43	4.64	5.25	4.57	4.08	2.70	2.77	3.44	3.68	3.54	3.57
1999	3.56	4.5	5.01	5.12	4.56	3.95	3.00	3.17	3.56	3.43	3.68	3.41
2000	3.74	4.21	4.89	4.10	4.56	4.07	3.15	2.82	3.49	3.36	3.39	3.30
2001	3.59	4.09	4.23	4.83	4.37	3.22	2.95	2.90	3.67	3.66	3.39	3.34
2002	3.32	4.17	4.36	5.04	4.83	3.94	3.45	3.19	3.57	3.76	3.54	3.46
2003	3.72	4.2	4.56	5.19	5	3.79	2.84	2.80	3.24	3.89	3.56	3.43
2004	3.64	4.21	4.77	4.49	5.04	3.62	3.23	3.04	3.39	3.66	3.40	3.31
2005	3.42	4.18	4.39	4.55	4.62	3.91	2.69	3.22	3.57	3.67	3.37	3.16
Mean	3.61	4.29	4.61	4.80	4.58	3.79	3.04	3.03	3.56	3.68	3.48	3.40
Fitted (@80%)	3.72	4.36	4.79	5.08	4.83	3.99	3.23	3.17	3.70	3.80	3.56	3.49

Based on ten years meteorological data of the area and fitted potential ET_0, crop water requirement and the respective irrigation schedules were worked out for potato using CROPWAT model (Tables 2 and 3). It was determined under the conditions of field efficiency of 70% and irrigating at critical depletion level to refill the soil moisture to the level of field capacity. The irrigation schedule for potato in Table 3 was determined on the basis of predetermined seven days irrigation interval and 0.5% yield loss level.

Three deficit water levels (20%, 40% and 60%) were applied at four potato growth stages namely: i) initial stage (IS) which includes the time from sowing to 10% ground cover, ii) crop development stage (CDS) which is from 10% to 70% ground cover, iii) mid-season stage (MSS) including flowering and yield formation, and iv) late season stage (LSS) including rippening and harvest. A satellite plot which is fully irrigated (0% deficit) was also included in the experiment.

Table 2. Crop water requirement and irrigation requirement of potato at Adet research station.

Month	Decade	Growth Stage	Kc	ET crop (mm/day)	ET crop (mm/dec)	Eff. rain (mm/dec)	Irr. req. (mm/day)	Irr. req. (mm/dec)
Dec	3	Initial	0.5	1.79	3.6	0.2	1.68	3.4
Jan	1	Initial	0.5	1.82	18.2	2.4	1.59	15.9
Jan	2	Initial	0.5	1.86	18.6	2.6	1.6	16.0
Jan	3	Initial/Dev.	0.59	2.32	25.5	2	2.13	23.4
Feb	1	Dev.	0.78	3.26	32.6	0.6	3.2	32.0
Feb	2	Dev.	1.0	4.39	43.9	0	4.39	43.9
Feb	3	Dev/Mid	1.13	5.12	40.9	2	4.86	38.9
Mar	1	Mid	1.15	5.37	53.7	5.8	4.79	47.9
Mar	2	Mid	1.15	5.52	55.2	8.2	4.7	47.0
Mar	3	Mid	1.15	5.63	62	10.7	4.66	51.3
Apr	1	Mid/Late	1.14	5.68	56.8	12.8	4.4	44.0
Apr	2	Late	1.06	5.39	53.9	15.1	3.88	38.8
Apr	3	Late	0.92	4.62	46.2	19.4	2.68	26.8
May	1	Late	0.8	3.94	31.5	19.3	1.53	12.2
Total					542.6	101.1		441.4

ET = Evapotranspiration, Kc = Crop coefficient, Eff. rain = Effective rain, Irr. Req. = Irrigation requirement, Initial = Initial growth stage, Dev. = Development growth stage, Mid = Mid growth stage, Late = Late growth stage.

Table 3. Irrigation schedule of potato at Adet research station.

Date	Day	Growth Stage	Rainfall (mm)	Depletion (%)	Kc frac	ETa (%)	Net irr. (mm)	Deficit (mm)	Loss (mm)	Gross irr. (mm)	Flow (l/s/ha)
5-Jan	7	Initial	0	24	1	100	11.5	0	0	16.4	0.27
12-Jan	14	Initial	0	22	1	100	11.6	0	0	16.6	0.27
19-Jan	21	Initial	0	20	1	100	11.7	0	0	16.7	0.28
26-Jan	28	Dev.	0	23	1	100	14.7	0	0	21.0	0.35
2-Feb	35	Dev.	0	26	1	100	18.1	0	0	25.9	0.43
9-Feb	42	Dev.	0	30	1	100	22.5	0	0	32.2	0.53
16-Feb	49	Dev.	0	37	0.96	99	29.4	0	0	42.1	0.70
23-Feb	56	Mid	1.0	38	0.97	100	31.7	0	0	45.3	0.75
2-Mar	63	Mid	0	41	0.92	99	34.8	0	0	49.8	0.82
9-Mar	70	Mid	0	41	0.93	99	34.2	0	0	48.9	0.81
16-Mar	77	Mid	0	40	0.94	99	33.9	0	0	48.4	0.80
23-Mar	84	Mid	5.7	39	0.96	99	32.8	0	0	46.9	0.78
30-Mar	91	Mid	0	40	0.95	99	33.5	0	0	47.8	0.79
6-Apr	98	Mid	0	39	0.96	99	32.7	0	0	46.8	0.77
13-Apr	105	Late	8.0	37	1	100	30.8	0	0	44.0	0.73
20-Apr	112	Late	0	35	1	100	29.7	0	0	42.4	0.7o
27-Apr	119	Late	10.9	14	1	100	12.2	0	0	17.4	0.29
4-May	126	Late	0	19	1	100	15.7	0	0	22.4	0.37
9-May	End	Late	0	9	1	0					
Total							441.5			631	

Initial = Initial growth stage, Dev. = Development growth stage, Mid = Mid growth stage, Late = Late growth stage, Kc = crop coefficient, ETa = actual evapotranspiration, Net irr.= net irrigation, Gross irr. = gross irrigation.

Treatments were arranged in randomized complete block design with three replications with a plot size of 3 m X 6 m each. Land preparation and planting were carried out early in December and at the end of December, respectively. Eighty potato seeds were planted along the ridge at 30 cm spacing and 75 cm between ridges in each plot. Fertilizer was applied at the rate of 69 kg P_2O_5 ha^{-1} and urea was split applied at the rate of 81 kg N ha^{-1} at planting and flowering stages.

Depending on the CROPWAT results, the irrigation schedule for each treatment setup was worked out (Table 4). Irrigation water was applied using furrow irrigation method and irrigation water was applied on weekly basis. The required amount of irrigation water for each treatment was applied to each furrow using a siphon. Geo-membrane was used as a lining material for the furrows to avoid lateral seepage of irrigation water to the adjacent plots. On average, three irrigations for establishment and fourteen irrigations afterwards were made throughout the potato growing season. Agronomic data such as number of tuber, tuber weight, total and marketable yield, unmarketable yield, dry matter content and water use efficiency were collected. The collected data were then subjected to statistical analysis using SAS software.

Results and discussion

Using the past ten years meteorological data, the daily maximum and minimum potential evapotranspiration rates were found to be 5.08 mm and 3.17 mm which occur during April and August, respectively. The average daily potential evapotranspiration was 3.98 mm. The seasonal crop evapotranspiration was then estimated to be 543 mm for Adet. Considering effective rainfall, the Cropwat model estimated 441 mm and 631 mm net and gross irrigation water requirements, respectively for potato at Adet.

Table 4. Amount of gross irrigation applied in liters for 18m^2 plot area at each potato growth stage in the season.

Date	Gross Irr. (lit)	Growth Stage	20% @ IS	40% @ IS	60% @ IS	20% @ CDS	40% @ CDS	60% @ CDS	20% @ MSS	40% @ MSS	60% @ MSS	20% @ LSS	40% @ LSS	60% @ LSS
5-Jan	295	IS	236	177	118	295	295	295	295	295	295	295	295	295
12-Jan	299	IS	239	179	120	299	299	299	299	299	299	299	299	299
19-Jan	301	IS	240	180	120	301	301	301	301	301	301	301	301	301
26-Jan	378	CDS	378	378	378	302	227	151	378	378	378	378	378	378
2-Feb	466	CDS	466	466	466	373	280	186	466	466	466	466	466	466
9-Feb	580	CDS	580	580	580	464	348	232	580	580	580	580	580	580
16-Feb	758	CDS	758	758	758	606	455	303	758	758	758	758	758	758
23-Feb	815	MSS	815	815	815	815	815	815	652	489	326	815	815	815
2-Mar	896	MSS	896	896	896	896	896	896	717	538	359	896	896	896
9-Mar	880	MSS	880	880	880	880	880	880	704	528	352	880	880	880
16-Mar	871	MSS	871	871	871	871	871	871	697	523	348	871	871	871
23-Mar	844	MSS	844	844	844	844	844	844	675	507	338	844	844	844
30-Mar	860	MSS	860	860	860	860	860	860	688	516	344	860	860	860
6-Apr	842	MSS	842	842	842	842	842	842	674	505	337	842	842	842
13-Apr	792	LSS	792	792	792	792	792	792	792	792	792	634	475	317
20-Apr	763	LSS	763	763	763	763	763	763	763	763	763	611	458	305
27-Apr	313	LSS	313	313	313	313	313	313	313	313	313	251	188	125
4-May	403	LSS	403	403	403	403	403	403	403	403	403	323	242	161
9-May		LSS										0	0	0
Total	11358		11179	11000	10821	10922	10485	10049	10156	8954	7752	10904	10449	9995

The agronomic results showed that the number of tubers per plant, average tuber weight, marketable yield, total yield, unmarketable yield and dry matter content were not affected significantly by deficit irrigation (Table 5). Generally, it was observed that the highest marketable yield, highest tuber number, and the highest total yield occurred with deficit application at crop development stage which gives an impression that deficit application at crop development stage is feasible (Table 5). On the contrary, the satellite plot (which is fully irrigated at all stages in the season) gave only 15.09 t/ha marketable yield and water productivity of 3.54. This relatively low yield may be attributed to the fact that potato yield and quality are susceptible to excess soil water as well. Excess soil water from frequent or intensive irrigation or rainfall during any growth stage leaches nitrate nitrogen below the plant root zone, potentially resulting in nitrogen-deficient plants, reduced fertilizer use efficiency. Saturation of the soil profile for more than 8-12hours can cause root damage due to a lack of oxygen required for normal respiration. Excess soil water at planting promotes seed piece decay and delays emergence due to decreased soil temperature (King and Stark, 1997).

Conclusion and recommendations

Most biological parameters respond non-significantly for the application of deficit irrigation application at different crop growth stages for both years. Hence, conclusion is made by critically looking into marketable yield, non-marketable yield, total yield, dry matter content and water use efficiency of potato. Accordingly, the combined analysis result of the two year data showed that, 60% deficit irrigation application at crop development stage (day 25 to day55) gave maximum marketable and total yield of 16.44 and 21.0 ton ha^{-1} respectively and dry matter content (22%) which is within the acceptable industrial standard (20-25%).

Table 5. Effect of deficit irrigation on yield and yield components of potato at Adet (2009 and 2010 combined).

Treatments	No. of tubers/plant	Av. tuber weight (g)	Marketable yield (t/ha)	Total yield (t/ha)	Unmarketable yield (t/ha)	Dry matter (%)	Water productivity (kg/m3)	Water saved (mm)
20% @ IS	8.6	62.4	15.11	19.85	4.74	22.3	3.61	7
40% @ IS	8.6	59.2	12.1	18.96	6.86	22.3	2.94	14
60% @ IS	8.4	57.8	12.34	18.17	5.83	21.6	3.05	21
20% @ CDS	9.1	53.2	13.76	18.45	4.69	22.1	3.36	17
40 % @CDS	8.7	58.6	15.12	19.15	4.03	20.6	3.86	34
60% @ CDS	9.9	55.6	16.44	21.02	4.58	22	4.38	51
20% @ MSS	9	62.9	14.37	19.95	5.58	22.2	3.79	47
40% @ MSS	8.5	62.5	15.13	19.97	4.84	22.3	4.54	93
60% @ MSS	8.7	56.3	12.57	18.68	6.11	22	4.4	140
20% @ LSS	8.6	58.8	14.76	20.42	5.66	20	3.58	14
40% @ LSS	7.4	65.6	12.89	17.05	4.16	22.3	3.25	22
60% @ LSS	8.5	58	15.32	19.13	3.81	22.5	4.01	37
LSD (5%)	NS	NS	NS	NS	NS	NS		
CV (%)	20.5	19.6	16.8	12.6	19	8.2		

Crops are more sensitive to water deficit during emergency, flowering and early yield formation than crop development and late stage (Doorenbos and Kassam, 1979). Hence, the result of this study goes in line with the above fact. Studies made at Colorado state university also indicated the critical period for potato is the time from tuber formation to harvest. Management allowable deficit (MAD%) for potato is found to be 40-60 % at early vegetative period, 30-40% at tuber bulking period and 65% at ripening period (Al-Kaisi and Broner, 2009). It can be seen that by applying 60% deficit irrigation at crop development stage, the crop used only 375 mm net irrigation water whereas full application with no deficit at all potato growth stage took net irrigation amount of 426 mm during the whole growing season. This implies that 51 mm irrigation water which is about 12% of the total net irrigation could be saved without significant potato yield loss at Adet. This is equivalent to saving 510 m^3 of irrigation water from a hectare of potato field. Therefore, application of 60% deficit irrigation at crop development stage (days 25 to 55) could be used to produce potato in Adet and areas having similar agro-ecology.

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