Water and nitrogen use efficiency in modern and Maori potato cultivars

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Abstract

There is renewed interest in heritage or Maori potato (*Solanum tuberosum* and *S. andigena*) cultivars in New Zealand because of the premiums growers receive relative to modern cultivars. However, there is little information on the agronomic performance of these heritage cultivars in modern production systems. This project compared yield, water use efficiency and nitrogen use efficiency of two Maori cultivars (Moemoe and Tutaekuri) and two modern potato cultivars (Moonlight and Agria). A glasshouse experiment was conducted at Massey University, Palmerston North, New Zealand from June to November 2009 comparing potato cultivars subjected to two irrigation and nitrogen regimes in a factorial design with four replicates. The irrigation treatments were 100% ET and 60% ET while applied nitrogen was 50 kg N ha^{-1} and 200 kg N ha^{-1} as urea. Tubers were planted in 15 l planter bags filled with 10 l of Manawatu sandy loam soil. Yield was recorded as total tuber weight (g) per plant. WUE as yield (g) per unit of water used (l) while NUE as yield (kg) per unit of applied nitrogen (g). Data were subjected to ANOVA using the PROC GLM procedure in SAS. Volumetric moisture content (%) was affected by cultivar ($P<0.0001$), irrigation ($P<0.0001$) and nitrogen ($P<0.0001$). Tuber yield, WUE and NUE differed significantly among cultivars ($P<0.0001$). Agria had higher yields, WUE and NUE than all cultivars while Tutaekuri had lower yields, WUE and NUE than all other cultivars, with Moonlight and Moemoe intermediate. The 100% ET irrigation treatment produced significant higher yields ($P<0.0001$) than 60% ET irrigation treatment and 200 kg N ha^{-1} produced significantly ($P<0.05$) higher yields than 50 kg N ha^{-1}. The WUE and NUE were influenced by irrigation and nitrogen in all cultivars, except in Tutaekuri ($P<0.05$). High irrigation reduced WUE but increased NUE. Similarly, high nitrogen reduced NUE but increased WUE in all cultivars.

***Additional keywords*:** *Solanum tuberosum*, *Solanum andigena*, Maori potatoes, irrigation, nitrogen, tuber yield, water use efficiency, nitrogen use efficiency

Introduction

Maori potatoes or Taewa are heritage cultivars used by Maori for over 200 years (Roskruge, 1999). Generally they yield less than recently developed cultivars; Harris and Niha (1999) found that modern potato cultivars yielded twice that of Maori potato. However, Taewa currently attract premium prices due to their novelty value as table potatoes as well as their cultural value. Consequently, there is interest in growing Maori potatoes for a niche domestic market and cultural economy (McFarlane, 2007). This is in contrast to modern cultivars which are typically produced on a large scale, mostly for domestic consumption either as table or process potatoes.

Potato yields are strongly influenced by water and soil nutrient availability and by genotypic variability (Bowen, 2003). Growers need to be able to manage inputs such as fertiliser and irrigation to reduce water loss and N leaching that both reduce profits and result in adverse environmental effects. Application of the concept of water (WUE) and nitrogen use efficiency (NUE) can help farmers optimise resource use and maximise profitability (Hoekstra and Chapagain, 2007). However, there is little information on the agronomic performance of the heritage Maori potato cultivars in modern production systems. A glasshouse experiment was conducted with an aim of comparing WUE and NUE in Taewa and modern potato cultivars subjected to different levels of irrigation and nitrogen (N) fertiliser.

Material and Methods

Location and establishment

The experiment was carried out in a glasshouse at the Plant Growth Unit, Massey University, Palmerston North from 23 June 2009 to 11 November 2009. Maori potato cultivars, Moemoe (*Solanum tuberosum* L.) and Tutaekuri (*Solanum andigena* Juz. & Buk.) and modern cultivars, Moonlight and Agria (*S. tuberosum*) were planted on 23 June 2009. Seed tubers (one per bag) were planted in 15 l plastic planting bags, partially filled with 10 l of air dried sieved (2 mm) soil; the soil type was a Manawatu sandy loam, a recent alluvial soil. The soil properties were: pH 5.4, Olsen P 36 mg l^{-1}, K 0.22 me $100g^{-1}$, and available nitrogen (N) 106 kg ha^{-1}. Bulk density was 1.35 g cm^{-3} and volumetric soil water content at field capacity and wilting point were 0.35 and 0.17 m^3 m^{-3}, respectively. Planting bags were arranged in a square grid pattern spaced at 70 cm. The glasshouse temperature was regulated between 15°C and 25°C for the entire period.

Treatments and experimental design

The experiment was laid out as a 2 x 2 x 4 factorial experimental design with four replicates (2 water regimes x 2 N fertiliser rates x 4 potato cultivars)**.** In addition, eight bags were planted with *Brassica napus* L. (two per replicate) as a reference crop because of its high potential water use for monitoring actual evapotranspiration (Wright *et al*., 1995).

Irrigation treatments were based on reference crop evapotranspiration (ET) and were implemented by applying 60% ET and 100% ET to plants every four days up to day 77 after planting, and subsequently, every two days. Irrigation to replenish the planting bags to field capacity was determined by weighing the *B. napus* reference bag before and after irrigation to obtain the mean reference crop evapotranspiration within the irrigation interval. The two N fertiliser application rates were 0.70 g N (50 kg N ha^{-1}) and 2.12 g N (200 kg N ha^{-1}) as urea. Urea was diluted to a concentration of 14 g l^{-1} in water and applied manually in a split application to minimize the risk of leaching.

All potato plants in the glasshouse were sprayed fortnightly, by hand, with an insecticide (pyrethroid) to control whitefly (*Bemisia argentifolii* Bellows & Perring) and Solanum psyllids (*Bactericera cockerelli* Sulc). Some of the Tutaekuri plants displayed symptoms (leaf curling and yellowing) of potato virus infection (N.

Roskruge pers. comm., 2009). Consequently all Tutaekuri plants were scored for severity of symptoms.

Soil moisture, tuber yield, water and nitrogen use efficiency

Volumetric soil moisture content in the bags was measured weekly using a time-domain reflectometer (TDR). Harvesting was done once after physiological maturity. The number of tubers plant^{-1}, individual tuber weight (g), and total tuber weight (g) were measured.

The WUE was determined as the total tuber yield (g) per unit of water used (l) and NUE was determined as the total tuber yield (g) as g N bag^{-1} (Darwish *et al*., 2006). Data was analysed with the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS, 1990) and differences among treatment means were compared by the Least Significant Difference test (LSD) at 5% probability.

Results

Evapotranspiration and Soil moisture content

Total cumulative evapotranspiration was 28.6 and 43.7 l for the 60% ET and 100% ET irrigation treatments respectively (Figure 1). Soil moisture content was significantly influenced by potato cultivar ($P<0.05$), irrigation ($P<0.0001$), and N ($P<0.0001$) between 20 and 85 days after planting. Soil moisture content in Tutaekuri bags was higher than all other cultivars (Figure 2). Irrigation increased the soil moisture content and N had no consistent effect on soil moisture content. There was a significant interaction between cultivar, irrigation and N on soil moisture ($P<0.01$).

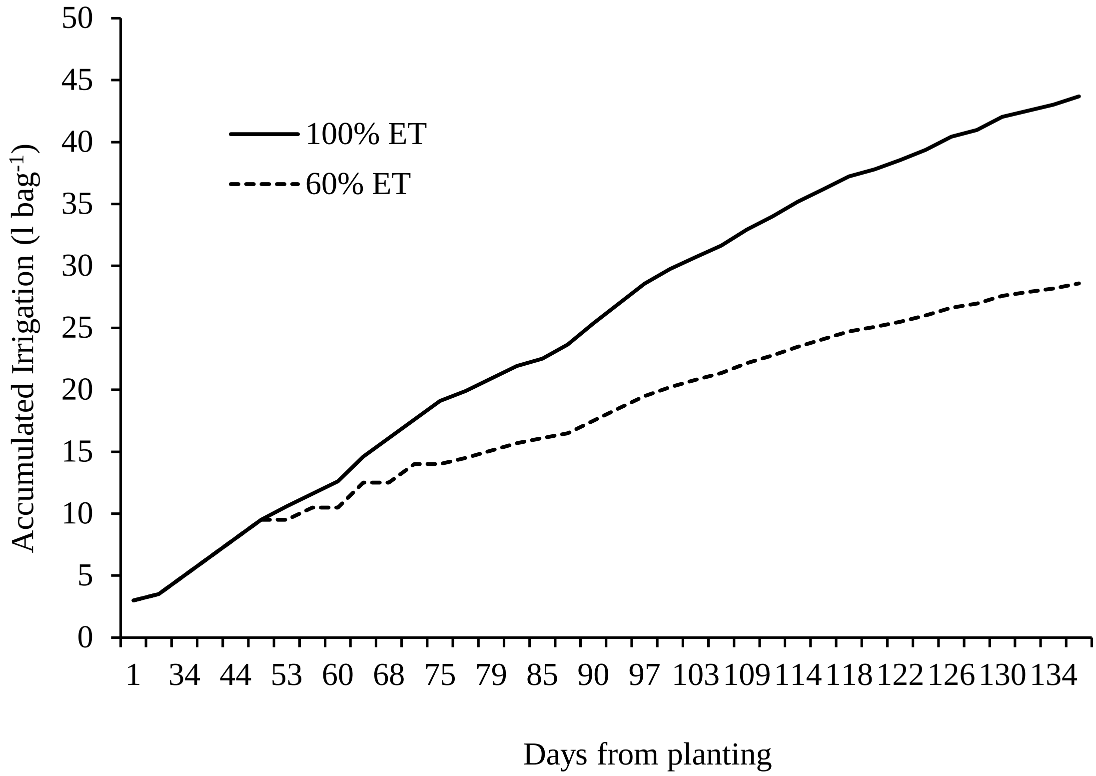

Figure 1: Total irrigation accumulated over days from planting.

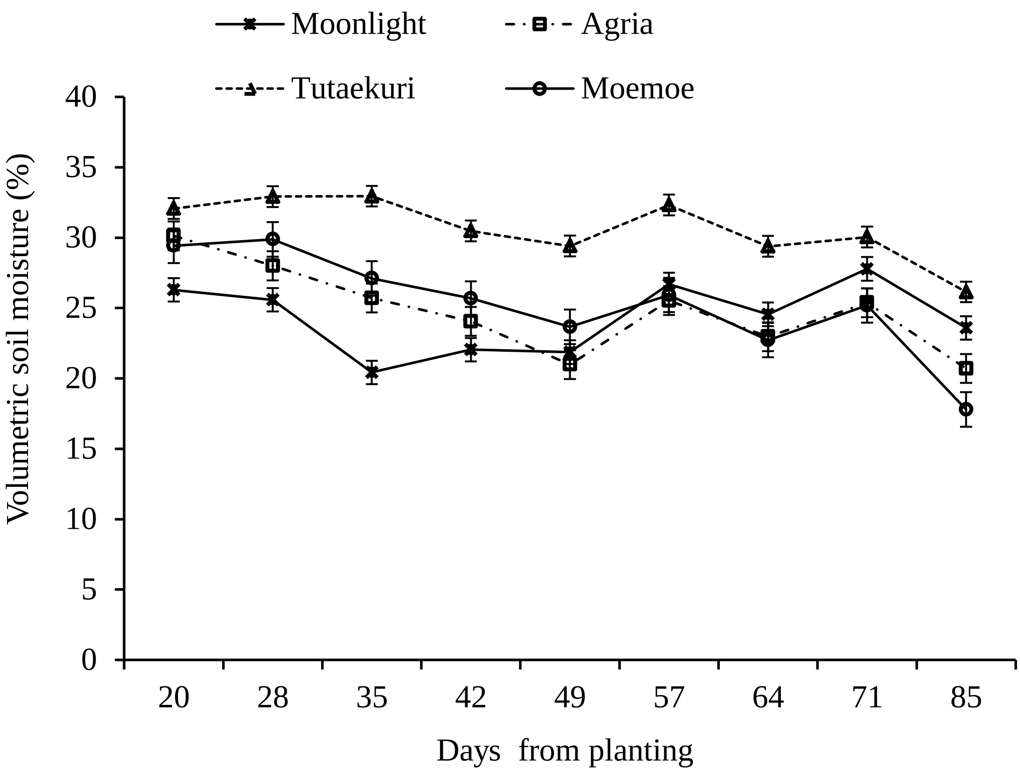

Figure 2: Change in volumetric soil moisture content (%) for each cultivar over time.

Tuber yield

The number of tubers $plant^{-1}$, mean tuber weight and total tuber weight were strongly affected by cultivar ($P<0.0001$). Irrigation ($P<0.0001$) and N ($P<0.05$) increased total tuber yield $plant^{-1}$ but did not influence the number of tubers $plant^{-1}$ or the mean tuber weight. Increased irrigation from 60% ET to 100% ET increased total tuber yield $plant^{-1}$ in all cultivars. Yields increased by 34.5%, 30.3%, 57.3% and 40.5% for Moonlight, Agria, Tutaekuri and Moemoe, respectively (Table 1). Similarly, N also increased total tuber yield $plant^{-1}$ in all cultivars though responses were generally less than those for irrigation (Table 1).

There were significant interactions between cultivar and irrigation treatments on the number of tubers $plant^{-1}$ ($P<0.01$) and mean tuber weight ($P<0.01$) (Table 1). Significant interactions were also observed between cultivar, irrigation and N on tuber number $plant^{-1}$ ($P<0.01$) and total tuber weight $plant^{-1}$ ($P<0.01$) (Figure 3). The interaction involving tuber yield resulted from the decrease in yield at thigh N and 100% ET irrigation in Tutaekuri, whereas in the other cultivars high N and 100% ET did not reduce, or increase, yield. In contrast, high N increased yield at 60 % ET in Tutaekuri. The mean tuber weight and total tuber yield $plant^{-1}$ in Agria were higher than in all other cultivars while Moemoe had the highest tuber numbers $plant^{-1}$.

Table 1: Yield response to irrigation and nitrogen regime in four potato cultivars under glasshouse conditions.

Cultivar	Irrigation	Tubers Plant^{-1}				Mean Tuber Weight(g)				Tuber Yield (g bag^{-1})			
Nitrogen (Kg N ha^{-1})		50	200			50	200			50	200		
Moonlight				(**)	(*)			(**)	(*)			(**)	(*)
	60% ET	13.0	12.8	12.9 a	11.1b	25.8	31.3	28.5b	44.3 b	320.8	360.3	340.5 b	399.3b
	100% ET	7.0	11.8	9.4b		72.4	47.5	60.0a		419.5	496.8	458.1 a	
	(**)	10.0[b]	12.3[a]			49.1	39.4			370.1 b	428.5 a		
Agria													
	60% ET	7.5	6.0	6.8	7.1c	59.5	75.2	67.4	70.0 a	396.3	410.5	403.4b	464.5a
	100% ET	7.0	8.0	7.5		73.6	71.5	72.6		486.8	564.5	525.6a	
	(**)	7.3	7.0			66.5	73.4			441.5 b	487.5 a		
Tutaekuri													
	60% ET	5.8	10.8	8.3b	9.2bc	19.8	27.4	23.6 b	30.2 b	119.0	244.0	181.5 b	233.5c
	100% ET	13.8	6.5	10.1a		25.1	48.7	36.9 a		330.0	241.0	285.5 a	
	(**)	9.8	8.6			22.5[b]	38.0[a]			224.5	242.5		
Moemoe													
	60% ET	9.3	11.8	10.5 b	14.3a	39.0	39.4	39.2	34.6 b	331.3	334.8	333.0 b	400.4b
	100% ET	15.8	20.3	18.0 a		34.2	25.8	30.0		432.5	503.3	467.9 a	
	(**)	12.5[b]	16.0[a]			36.6	32.6			381.9 b	419.0 a		
Significance	Cultivars				P<0.0001				P<0.0001				P<0.0001
	Irrigation				NS				P≤0.07				P<0.0001
	Nitrogen				NS				NS				P<0.01
	Cultivar*Irrigation				P<0.01				P<0.01				NS
	Cult*Irr*N				P=0.01				NS				P<0.01
$LSD_{0.05}$	Cultivar				2.8				16.1				46.5
	Nitrogen				-				-				32.9
	Irrigation				-				11.4				32.9

Note: Column rows with same letters are not significantly different. **N=16, *N=32.

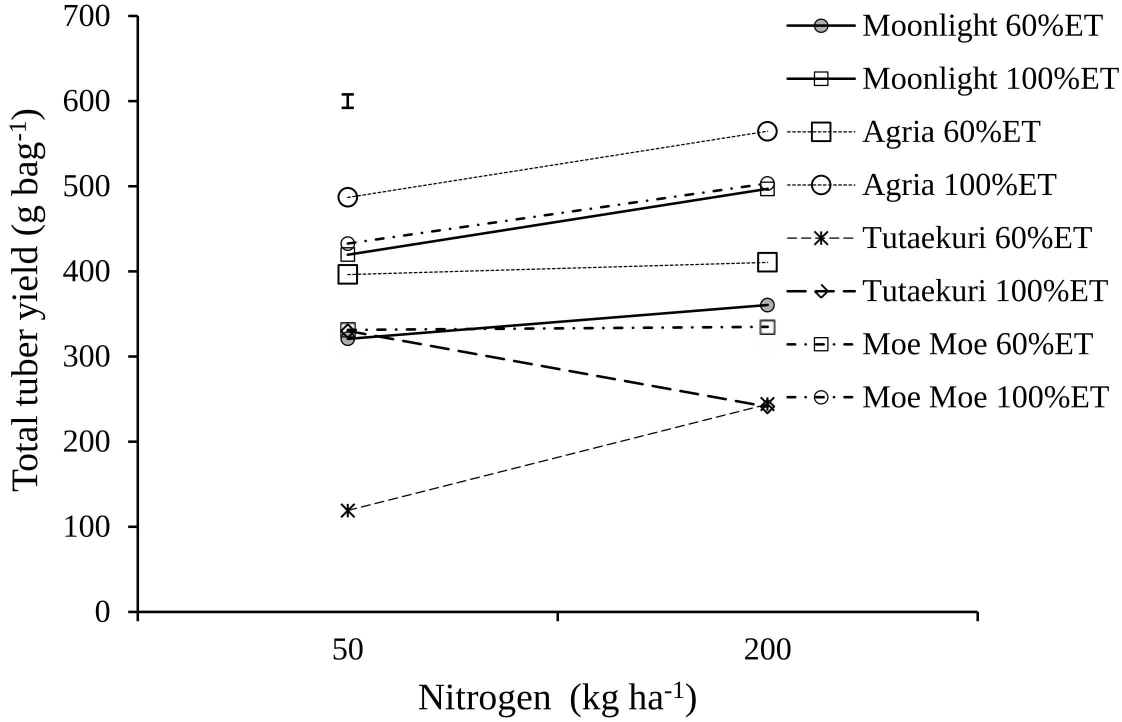

Figure 3: Interaction between cultivar, irrigation and nitrogen regime on total tuber yield (g bag^{-1}). Error bar ±SEM.

Water and nitrogen use efficiency

The WUE reflected tuber yields and was highest in Agria, significantly higher (P<0.0001) than in Moonlight and Moemoe. Tutaekuri was significantly lower than all other cultivars (Table 2). The WUE was also significantly affected (P<0.05) by irrigation and N in all cultivars except in Tutaekuri where irrigation had no effect on WUE. Increasing irrigation from 60% ET to 100% ET reduced WUE by 11.8% in Moonlight, 14.9% in Agria, and 8.5% in Moemoe (Figure 4). The high N fertiliser rate increased WUE by 15.4% in Moonlight, 8.8% in Agria, 8.4% in Moemoe and 22.8% in Tutaekuri (Figure 4).

Similarly NUE was significantly higher (P<0.0001) for Agria than for Moemoe and moonlight, which were significantly higher than Tutaekuri.

The NUE was significantly affected by irrigation (P<0.0001) and N fertiliser (P<0.0001). There was a significant interaction between irrigation and N (P<0.0001) and between irrigation, N and cultivar (P<0.01) on NUE (Figure 5). Increased irrigation increased the NUE by 29.6% in Moonlight, 26.2% in Agria, 60% in Moemoe and 104.2% in Tutaekuri. However, high N reduced NUE by 67.7% in Moonlight, 67.6% in Agria and 70.2% in Tutaekuri, but increased NUE by 50% in Moemoe.

The relationship between WUE and NUE was explored using simple correlation. With all data combined no correlation between WUE and NUE was found. However, when data were stratified by N treatments moderately strong (P<0.01) correlations were identified; low N (r=0.71) and high N (r=0.72). Data stratified by irrigation analysis showed no correlation between WUE and NUE.

Table 2. Water use efficiency (WUE) and nitrogen use efficiency (NUE) of four potato cultivars.

Cultivar	Irrigation	WUE(g l^{-1})				NUE (g g^{-1} N)				Visual Disease Scores
Nitrogen (Kg N ha^{-1})		50	200			50	200			
Moonlight				(**)	(*)			(**)	(*)	
	60% ET	11.2	12.6	11.9a	11.2 b	0.81	0.26	0.54 b	0.62 b	0
	100% ET	9.6	11.4	10.5b		1.05	0.35	0.70 a		0
	(**)	10.4 b	12.0 a			0.93 a	0.31 b			
Agria										
	60% ET	13.9	14.4	14.1 a	13.1 a	0.99	0.30	0.65 b	0.73 a	0
	100% ET	11.1	12.9	12.0 b		1.23	0.41	0.82 a		0
	(**)	12.5 b	13.6 a			1.11 a	0.36 b			
Tutaekuri										
	60% ET	4.2	8.5	6.4	6.4 c	0.30	0.18	0.24 b	0.37 c	3.0
	100% ET	7.6	5.5	6.5		0.83	0.15	0.49 a		2.7
	(**)	5.9 b	7.0 a			0.57 a	0.17 b			
Moemoe										
	60% ET	11.6	11.7	11.7 a	11.2 b	0.83	0.24	0.54 b	0.63 b	0
	100% ET	9.9	11.5	10.7 b		1.08	0.36	0.72 a		0
	(**)	10.7b	11.6a			0.96 a	0.30 b			
Signif.	Cultivar				P<0.0001				P<0.0001	P<0.0001
	Irrigation				P=0.05				P<0.0001	NS
	Nitrogen				P=0.01				P<0.0001	NS
	N*Irr				NS				P<0.0001	NS
	Cult*N				NS				P<0.0001	NS
	Cult*Irr*N				P=0.01				P=0.01	NS
LSD	Cultivar				1.3				0.068	-
	Irrigation & nitrogen				0.9078				0.048	

Note: Column rows with same letters are not significantly different. **N = 16, * N = 32.

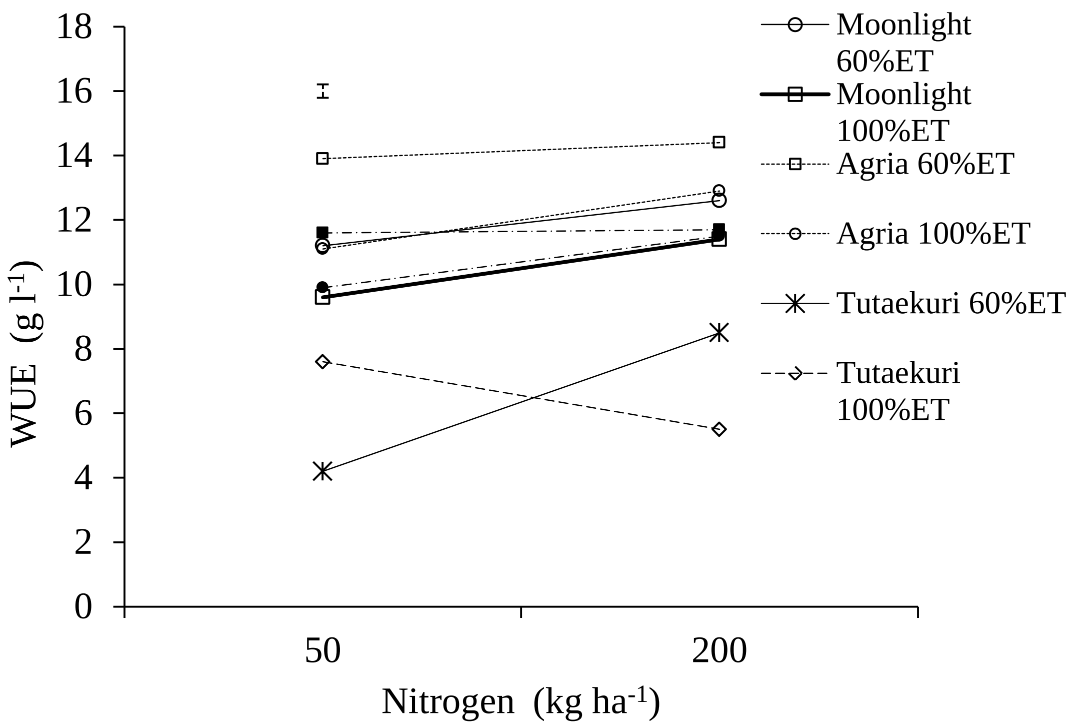

Figure 4: Interaction between cultivars, irrigation and nitrogen regime onWUE (g l^{-1}). Error bar = ±SEM.

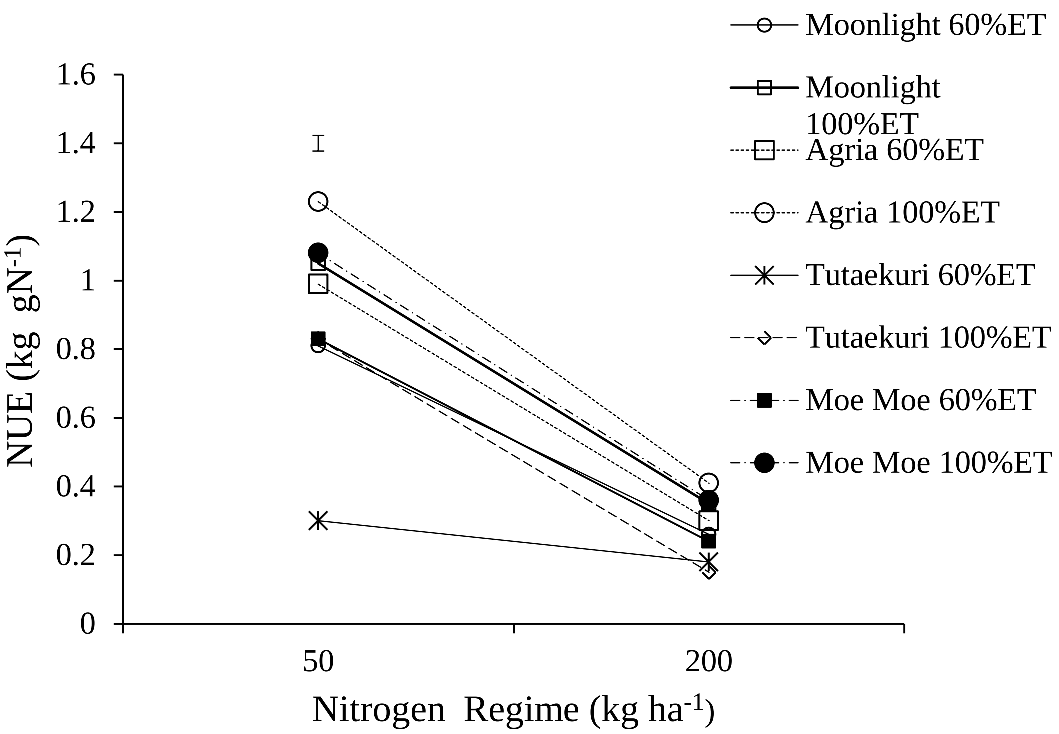

Figure 5: Interaction between cultivars, irrigation and nitrogen regime on NUE (kg g^{-1} N). Error bar = ±SEM.

Discussion

Manipulation of irrigation and N had a significant effect on tuber yield in all cultivars but the mechanism varied with cultivar. For example, Moemoe responded primarily through an increase in tuber numbers whereas Moonlight responded by producing more tubers and increased tuber weight in response to irrigation. Increased yield in response to irrigation and N results from increased partitioning of assimilates to the roots and tubers but the influence on yield components can vary with cultivar (Bélanger *et al.,* 2002).

The relatively poor yield of Tutaekuri at 100 % ET and high N may have been the result of a virus infection in plants used in this treatment combination (Ovenden *et al*., 1985) or infected seed tubers used (N Roskruge, pers. comm., 2009). Visual observation showed virus symptoms in this treatment whereas no virus symptoms were observed in plants in any other treatment.

Mean WUE varied with yield and ranged from 13.1 g l^{-1} (Agria) to 6.4 g l^{-1} (Tutaekuri). This equates to 7.6 and 15.6 l respectively to produce a 100 g tuber and is lower than an estimate of the mean global virtual water content of 25 l for a 100 g potato tuber (Hoekstra and Chapagain, 2007).

Water use efficiency was highest under restricted irrigation but a consequence of this was that NUE was reduced. Battilani *et al*. (2004) also reported that WUE was higher in non-irrigated than in well watered potato crops. Integration of all factors, including genotype and non-water inputs such as fertiliser, can help to achieve optimum production (Wallace, 2000; Morison *et al*., 2008). This strategy helps the use of the correlation between WUE and NUE reported in this and other studies (Battilani *et al*., 2004). The adoption of high yielding cultivars can be based on selecting cultivars with high WUE and high NUE, as well as high soil water abstraction. In this study tuber yield and WUE were relatively high in three cultivars and the WUE was affected by the irrigation regime, whereas the low yielding cultivar had a low WUE, irrespective of irrigation level. This suggests that manipulation of the environment might not affect yield and WUE in potato cultivars with a low potential yield as much as in cultivars with high potential yield (Steyn *et al*., 1998). Consequently, growers need to consider both soil water management and potato genotype in optimising resource use and maximising profitability.

In this study tuber yield response to irrigation was greater than that of N. The requirement for adequate water in potatoes is well documented (Vos and Groenwold, 1989; Ferreira *et al*., 2007;) whereas high rates of N can decrease yield in potatoes (Manochehr Shiri-e-Janagrad *et al*., 2009). During sunny days the temperature in the glasshouse was generally above 20°C and this suggests that evapotranspiration and therefore requirement for irrigation water would have been high, especially when the potatoes were in full canopy. This is supported by the gradual decline in soil moisture between 20 and 50 days after emergence.

This study suggested that Moemoe had similar productivity and resource use efficiency to Moonlight and Agria, despite the fact that it is a heritage cultivar. This agrees with the suggestion that high yield and WUE apparent in most modern cultivars relies on a combination of factors, including appropriate site selection, pest and disease control and optimum management of inputs, rather than simple genetic improvement to achieve high yield and WUE (Richards *et al*., 2002; Barker *et al*., 2003). The performance of Moemoe indicates that with appropriate management of inputs its use may allow growers to access high value niche markets (McFarlane, 2007) without necessarily suffering low yield and resource use efficiency.

Conclusions

The results indicate that irrigation and N application improves Maori potato and modern potato cultivars yields. Total tuber yields were highest in Agria and Moemoe and resulted from a high mean tuber weight and a high tuber number plant^{-1}, respectively. Increased water supply increased yield and NUE while decreasing WUE. Cultivars with a high WUE also had a high NUE.

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