Effect of tramline management and irrigation method on runoff

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Final report

Executive summary

Tramline management cultivation methods; the Briggs tied-ridger, Aqua Agronomy Wheel Track Roller and Bye Engineering Wonder Wheel were evaluated across both boom and rain gun irrigated Russet Burbank potatoes grown on a sloping, sandy field in Suffolk during April - September 2017. Tramline management treatments were imposed post-planting and involved cultivating and profiling the furrows between beds in non-spray wheelings. These were compared to two treatments that were trafficked approximately 2 weeks post emergence; a trafficked without disturbance and trafficked with a subsequent Wonder wheel pass. Six diffuse pollution sampling events were undertaken between June and October 2017. Above ground crop assessments were undertaken every 3-4 days followed by a harvest on the 5th October.

Key experimental outcomes were as follows

- Trafficked treatments without disturbance were associated with significantly higher runoff volume, sediment concentration, total soil loss (TSL) and total oxides of nitrogen (TON) concentration in runoff as compared to all other treatments.
- Trafficked treatments disrupted with the wonder wheel (irrespective of irrigation method) reduced diffuse pollution to the same levels observed in the post-planting Tied-ridger, Wheel Track Roller and Wonder Wheel treatments without further trafficking.
- Despite 100 % canopy cover levels of sediment concentration and orthophosphate at levels considered ‘polluting’ were observed from all treatments in at least one of the 6 sampling events.
- Boom irrigated treatments were associated with a significant 43 % increase in cumulative TSL and a significant 47 % increase in cumulative runoff TON concentration as compared to gun-irrigated treatments. Boom irrigation

significantly increased runoff sediment concentration by 69 % in Sampling Event 5 as compared to gun-irrigated treatments. Therefore, in the context of this field trial, boom irrigation can be considered to be more erosive than gun irrigation.

- No effects on yield, tuber quality or fry colour were observed. However, secondary-trafficked rows without Wonder Wheel amelioration had numerically lower yield than the Wonder Wheel ameliorated treatment.

Recommendations

- Further research is required to fully evaluate the efficacy of the treatments tested for a range of soil types, slopes, potato varieties (and associated bed-forms) across the entire cropping cycle from pre-emergence to harvest. Such research will significantly increase the confidence of recommendations to adopt wheeling disruption as a best management practice for prevent erosion and diffuse pollution control as well as increase water use efficiency in potato production.
- Further research is required to investigate the drop size distributions, impact velocities and kinetic energy associated with boom-irrigation nozzles across a range of application rates such that ‘erosivity’ of boom irrigation can be reduced without compromising irrigation efficiency and uniformity. This is of particular relevance during scab control periods when plant canopy is not fully developed.

Materials and Methods

The experiment was conducted in Dando field on the Elveden Estate, Suffolk (52°19'39.97"N, 0°36'10.55"E). This field was pre-selected by the Norfolk Rivers Trust, based upon the high runoff risk posed for diffuse pollution as indicated by SCIMAP (Figure 1). The field was 250 m in length with an average slope of 4% (2.3 degrees) that flattened out towards the bottom of the field (Table 1). Soil textural analysis indicated that the soil was a Sandy Loam/Loamy Sand (79 % sand, 12 % silt and 10 % clay) with a 5 % stone content and 3.18 % organic matter (0-15 cm depth).

Table 1. Variability in field slope across Blocks 1 and 2. Different letters denote a significant difference ($p<0.05$) following analysis of variance (ANOVA).

Sub-plot	Slope (n=3) (%)
A	4.6a
B	5.2a
C	3.7b

The field was planted in 1.83 m wide, 3 row beds on 6 April using 35-50 mm Russet Burbank seed at a within-row spacing of 33 cm. Standard farm fertilizer and agrochemical applications were made throughout the experiment.

Treatments

The treatments evaluated in this trial are detailed in Table 2 and illustrated in Figure 3. All treatments were replicated in triplicate. The selection of machines was based on the knowledge of current industrial practice. Elveden have had a Briggs Tied Ridger (TR) for a number of years and use it occasionally on sloping fields in a high risk area. Andrew Francis (Elveden Farm Manager) observed the Aqua Agronomy Wheel Track Roller (WTR) in winter 2016 at a Catchment Sensitive Farming event. He had been aware of the Bye Engineering Wonder Wheel (WW) for a year or so and wanted to test this in ‘dummy’ tramlines to see if he could have a positive impact by looking at retrospective action during the season. In terms of tramline management, the TR is very difficult to drive over once treated, so is impractical and the WTR seemed to make so little impact that it was thought that its effect wouldn’t last long in a wheeling and was therefore not worth trying.

Table 2. Treatments evaluated in this trial.

Treatment	Code	Description	Date imposed
Tied ridger	TR	Briggs tied-ridger (Figure 3) applied post planting and following irrigation.	13th April 2017
Wheel Track Roller	WTR	Aqua Agronomy Wheel Track Roller (Figure 3) applied post planting and following irrigation.	13th April 2017
Wonder Wheel	WW	Bye Engineering Wonder Wheel (Figure 3) applied post planting and following irrigation.	13th April 2017
Control	CT	No disturbance applied post planting.	13th April 2017
Trafficked	T	Trafficked with four passes by a 14 t sprayer with no subsequent disturbance.	23rd May 2017
Wonder Wheel Trafficked	WWT	Trafficked with four passes by a 14 t sprayer and later disrupted by the Bye Engineering Wonder Wheel	23rd and 24th May 2017

Note: Post-planting the field was irrigated as the field was too dry for effective treatment application.

Wheeling treatments were applied up and down slope in two blocks (Figure 2) to facilitate an evaluation of their efficacy to minimize diffuse pollution risk across both boom and gun irrigation. The resulting soil disruption patterns are presented in Figure 4 (post-planting) and Figure 5 (post trafficking). Within each block, treatments were divided into 3x 80 m long sub-plots (A, B and C) where data collection was carried out (Figure 6).

Machinery observations

All machines selected were fairly easy to operate. The WTR and the WW both picked up moist soil, although with the WW it may have been because it was new and soil stuck to the paint. The WTR rollers needed clearing of soil each end of the field as the rubber didn’t seem flexible enough to crack it off. This could have been a result of it being an old machine. The WW did not have an effect on traffic after use and was relatively smooth to drive on. There is some concern that the WW may erode the sides of the beds/ridges slightly, which may lead to increased greening or scab and this would need quantifying in the project.

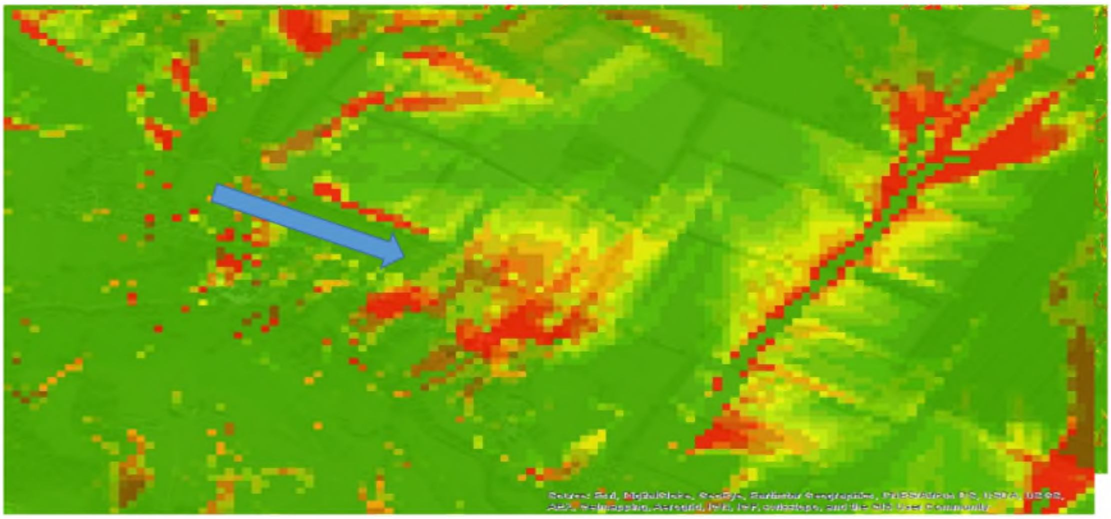


Figure 1. SCIMAP output showing the runoff risk from Dando. Source: Ed Bramham-Jones, Norfolk Rivers Trust.

Figure 2. Location of treatment blocks within 'Dando' Field Block 1 = Boom irrigated and Block 2 = Gun irrigated.

The Boom and Gun irrigation treatments were both manufactured by Briggs and retracted using Briggs hosereels. After discussion, the application rates were set for 15 mm for both machines rather than 25 mm for the Gun. Irrigation events for both machines took place on the same day, except for 22nd and 26th June, when the Boom was run the day after the Gun. Irrigation for both irrigation treatments was scheduled by Elveden Estate.

Figure 3. Tramline management cultivation methods.

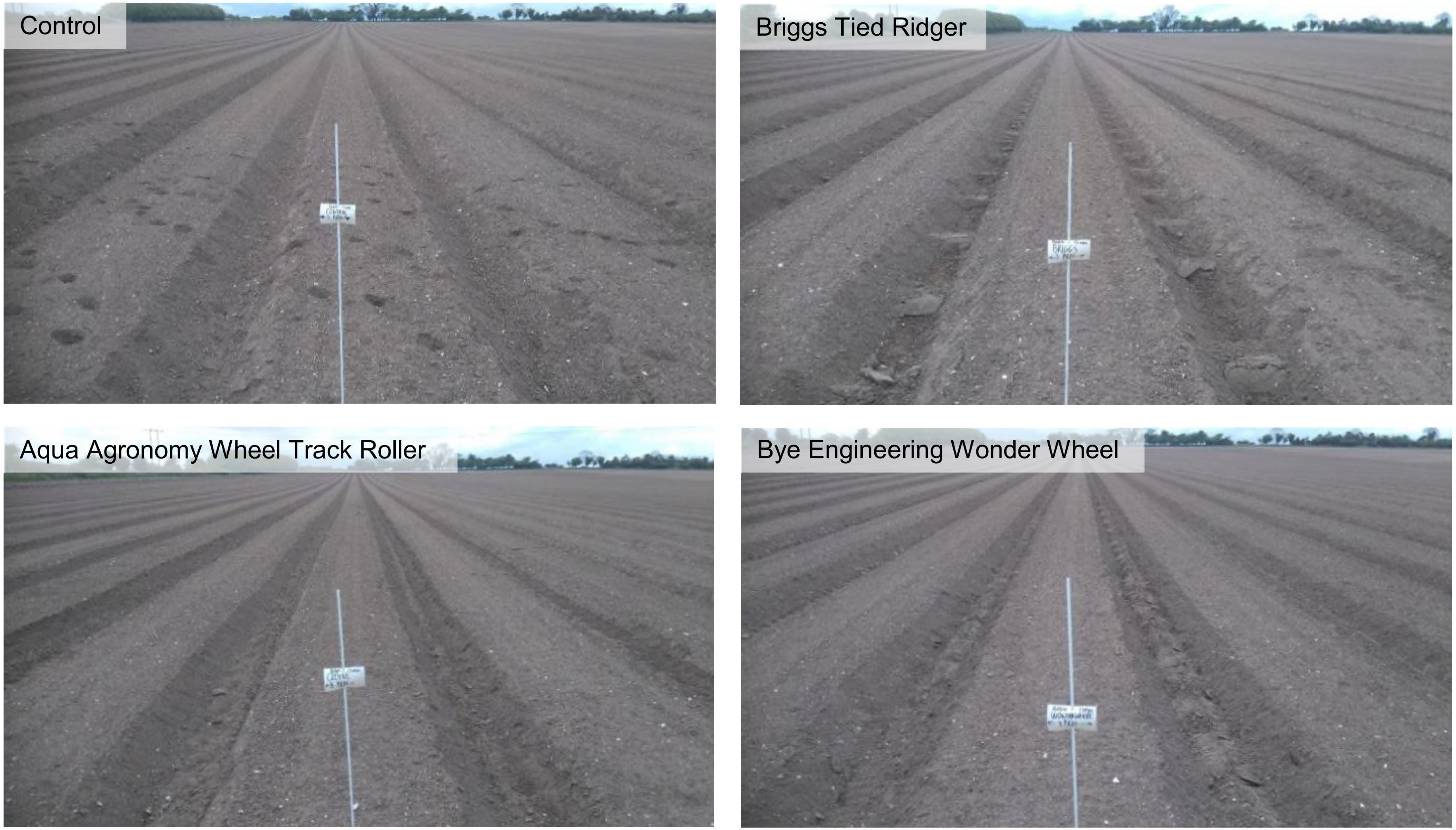


Figure 4. Tramline management treatments post application in non-trafficked wheelings.

Figure 5. Tramline management treatments post application in trafficked wheelings. Trafficked (T) is shown on the left and trafficked followed with the Bye engineering Wonder Wheel (WWT) on the right.

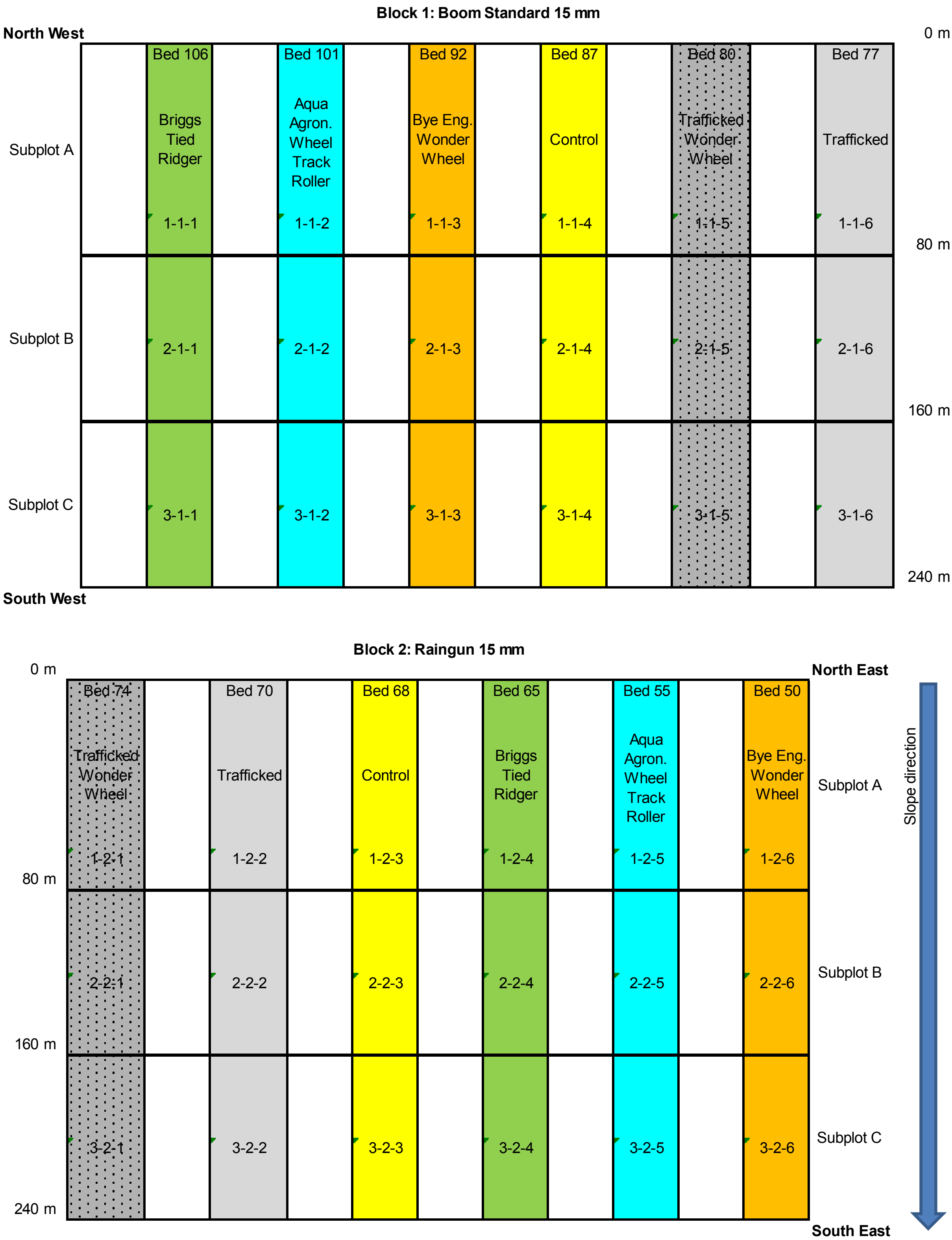


Figure 6. Treatment layout and subplots within each experimental block.

Soil moisture deficits and crop water use

Using the meteorological data from the on-site Adcon weather station managed by Plant Systems, combined with the ground cover measurements from CanopyCheck™, the NIAB CUF Irrigation Model was used to produce estimates of soil moisture deficits (SMD) and daily water use by the crop. Rainfall data were collected from an electronic raingauge 400 m away and supported by irrigation data supplied by Elveden staff.

Crop measurements

Plant emergence was recorded every 3-4 days in each Control plot by counting the number of plants emerged in 5 m of bed. Ground cover was measured using the NIAB CUF CanopyCheck™ i-Pad app, initially weekly after emergence until full canopy and then every two weeks until desiccation using. Measurements were taken in the middle of each plot.

A final harvest of 1.5 m of bed (area 2.74 m^2) was taken from the middle bed of each plot on 5 October and plant and stem counts were made. On 7 November, all tubers were graded, counted and weighed in 10 mm increments. All tubers >90 mm long were counted and weighed to determine the proportion of tubers in the highly-valuable McCain ‘Gold Standard’ category. A representative sub-sample of tubers weighing c. 1 kg was dried at 90 °C for 48 h to measure tuber dry matter concentration ([DM]). All remaining tubers >50 mm long were stored at 8.5 °C with no sprout suppressant until 8 December.

On removal from storage, all tubers were assessed for greening and secondary growth defects. Twenty random tubers were sliced in half longitudinally and assessed for symptoms of Brown Centre and Hollow Heart.

A further 10 random tubers from each plot were washed, peeled and chipped using a Robocoupe CL50 food processor with a 10 mm slicing plate and chipping grid. Two random, full-length chips from each tuber were selected. All 20 chips were washed for 45 s in cold tap water and drained for 2 minutes. They were then fried for 3 min in sunflower soil at a starting temperature of 190 °C and a finishing temperature of c.

180-185 °C. All 10 chips in each sample were then scored using a USDA Munsell Color chart (4th Edn, 1988), according to the defined protocol.

Variates were analysed by analysis of variance using the GenStat® Release 16.1 statistical package. Treatment means are stated to be significantly different only if the probability of differences occurring by chance were less than 5 % ($P < 0.05$).

Diffuse pollution measurement

Fully instrumented runoff and erosion plots were installed (Figure 7) on x3 30 m lengths within each treatment block. Each plot was hydrologically sealed by a soffit board angled at the top of each plot to divert any above plot runoff into the neighbouring tramline (Figure 8). Gerlach troughs (Figure 9) were installed in one wheeling per sub-plot and connected to (250 l) runoff tanks via 68mm diameter pipes. Therefore, results generated represented 50% of the treatment area, and were doubled in order to evaluate treatment performance.

Figure 7. A typical runoff and erosion plot layout.

Composite soil, bulk density (BD) and penetrative resistance (PR) measurements were taken from each experimental plot. Bulk density (0-5 cm depth) and soil moisture measurements were taken on the 4th – 5th September, in the middle of each wheeling at 6, 16 and 26 m from the Gerlach trough.

Figure 8. Soffit board installation to divert runoff from upslope flowing onto the plot.

Figure 9. Gerlach trough bedded into the wheeling to capture runoff from within the 30m plot.

Digital PR measurements were taken over two visits (26th July and 4th August) using an Eijkelkamp Penetrologger with a 1.2 cm^2 30° internal angle cone. PR measurements were made at 6 points along each experimental plot starting 5.0 m from the Gerlach trough. PR measurements at each sampling point were recorded at 0.01 m intervals to a depth of between 0.24 and 0.45 m due to the presence of a stone layer. From each PR profile an average was taken and the maximum, minimum and median values for each plot tested for significance using One-way ANOVA and post-hoc Fisher LSD analysis.

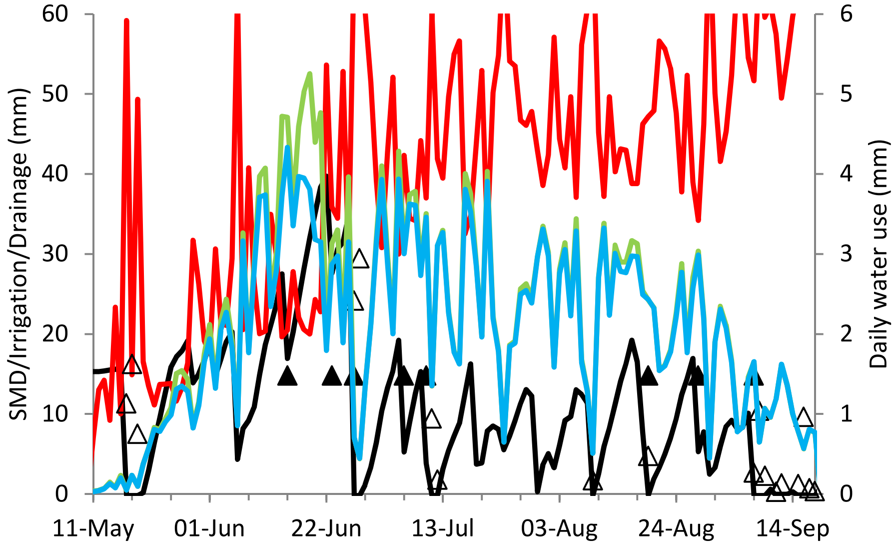
Treatment performance was evaluated in terms of runoff volume (l per $plot^{-1}$), total soil loss (kg per $plot^{-1}$), sediment concentration (mg l^{-1}), runoff TON concentration (mg l^{-1}) and runoff orthophosphate concentration (mg l^{-1}).

Results

Soil moisture deficits and irrigation events

A total of 120 mm of irrigation was applied between emergence and desiccation in both application methods. Shortly after tuber initiation, the soil was returned to an SMD of < 5 mm by rainfall, but there followed a very hot 2-week period in mid-June (with evapotranspiration rates > 5 mm/day), which stressed the developing crop slightly even though irrigation was applied, slowing the closure of the canopy. Thereafter, through well-scheduled irrigation, plots were maintained < 20 mm soil moisture deficit and there should have been no subsequent restriction to canopy expansion or yield as a consequence of lack of water (Figure 10). From mid-July until mid-August, no irrigation was required owing to rainfall and low evaporative demand. Assuming that no run-off occurred (which was clearly not the case in trafficked wheelings), there would have been c.138 mm of drainage below rooting depth from emergence to desiccation. A total of 332 mm of rain fell during this period. The two largest drainage (and potential run-off) events occurred on 27-28 June (Figure 10) following 75 mm of rain immediately succeeding an irrigation event. The potential water use of the crop canopies that developed in the experiment would have been c. 285 mm and through the irrigation regime practiced, c. 94 % of the potential water use would have been met.

a)



b)

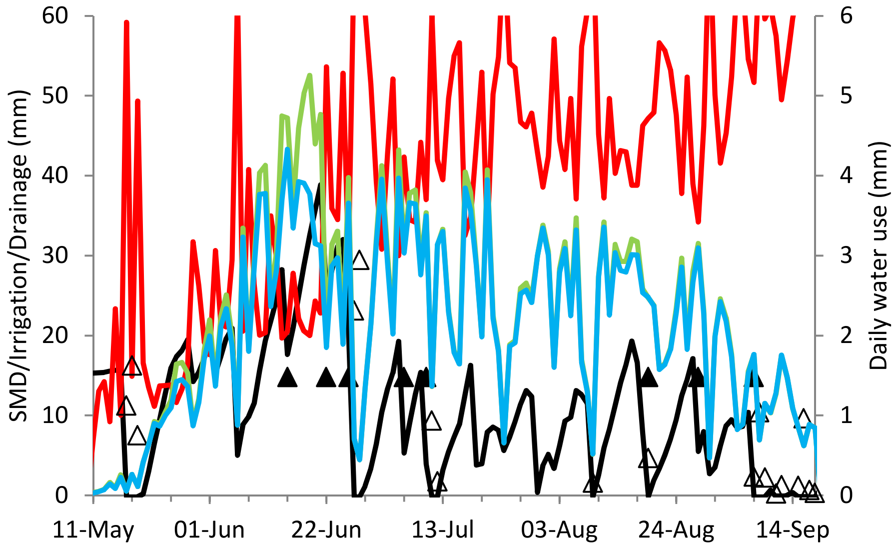


Figure 10. Modelled soil moisture deficits, daily water use and irrigation and drainage events from emergence until final harvest. Soil moisture deficit, ▬; limiting deficit, ▬; irrigation ▲; drainage, Δ; potential daily water use, ▬; actual daily water use, ▬. a) Boom; b) Gun.

Crop variables

Emergence, tuber initiation and ground cover

Emergence commenced 7 May and was 100 % complete by 14 May. The date of 50 % emergence was 11 May (± 0.6 days). Ground cover increased at 4 % per day during the linear phase of expansion and all plots reached 100 % ground cover by 16 June. Crops started to senesce slowly in mid-August and were at 70-75 % cover by desiccation on 18 September (Figure 11). There was no effect of irrigation method on ground cover development or duration (ground cover was not measured in all tramline management plots).

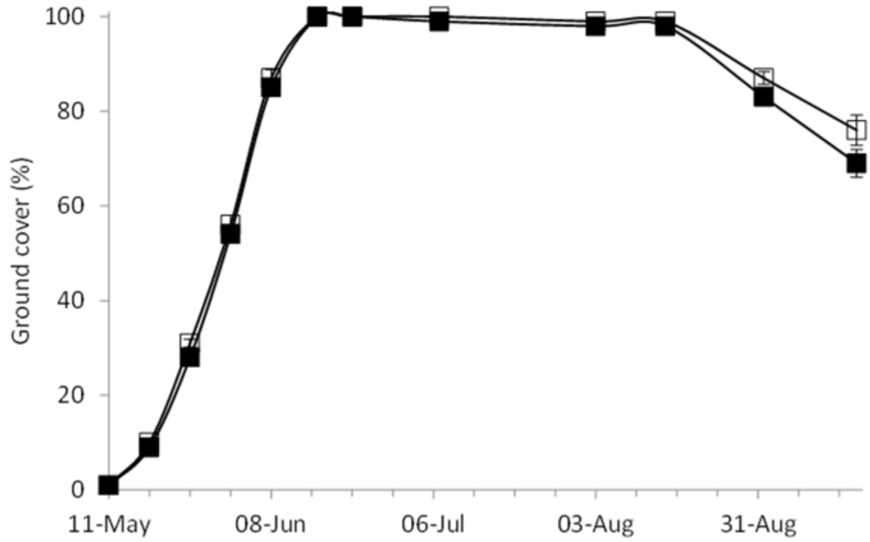


Figure 11. Effect of irrigation method on ground cover. Boom, ■; Gun, □. Error bars are based on 2 D.F.

Number of tubers and tuber yield

There was no significant effect of treatment on the number of plants or stems, nor the number of tubers produced (Table 3). There was no effect of irrigation regime on total or ware yields (but Gun was consistently numerically higher yield than Boom, although these were situated in different areas of the field). There was also no effect of tramline management on yield, but there was an indication that secondary-trafficked rows without Wonder Wheel amelioration had numerically lower yield than the other tramline management regimes (Table 3).

Table 3. Effect of irrigation method and tramline management on number of stems and tubers, tuber yield and dry matter concentration at final harvest. S.E. based on 20 D.F., except for Irrigation main effect, where 2 D.F.

Irrig	Treatment	Plants (000/ha)	Stems (000/ha)	Total. tubers (000/ha)	Tubers >40 mm (000/ha)	Total yield (t/ha)	>40mm yield (t/ha)	Tuber DM (%)	DM yield (t/ha)	Tubers >90mm (%)
Boom	CT	33	66	395	289	72.9	70.3	20.9	15.2	84
	TR	33	80	388	275	71.3	68.4	21.3	15.2	78
	WTR	34	94	431	315	71.1	68.1	21.8	15.5	84
	WW	34	81	468	361	77.7	75.2	21.3	16.6	82
	T	33	72	386	290	69.9	67.3	21.1	14.8	89
	WWT	33	78	417	312	73.8	71.5	21.6	15.9	85
Gun	CT	33	90	445	318	75.9	72.7	20.9	15.9	91
	TR	34	85	407	311	74.9	72.3	21.6	16.2	83
	WTR	33	87	420	329	77.2	74.7	21.5	16.6	79
	WW	34	84	448	355	82.9	80.6	21.3	17.7	85
	T	33	74	388	289	71.0	68.7	21.0	14.9	84
	WWT	34	96	464	358	81.2	78.3	21.1	17.1	80
S.E.		0.80	7.1	40.0	23.9	4.26	4.00	0.54	1.12	4.1
S.E. (same irrig.		0.81	7.2	43.2	25.7	4.28	4.06	0.57	1.13	4.3
Boom		33	78	414	307	72.8	70.1	21.3	15.5	84
Gun		33	86	429	327	77.2	74.6	21.2	16.4	84
S.E.		0.29	2.7	7.0	4.8	1.70	1.52	0.15	0.46	1.2
	CT	33	78	420	304	74.4	71.5	20.9	15.5	87
	TR	33	83	397	293	73.1	70.3	21.4	15.7	80
	WTR	33	91	426	322	74.2	71.4	21.6	16.0	82
	WW	34	83	458	358	80.3	77.9	21.3	17.1	84
	T	33	73	387	290	70.5	68.0	21.1	14.8	86
	WWT	33	87	440	335	77.5	74.9	21.3	16.5	82
S.E.		0.57	5.1	30.5	18.1	3.03	2.87	0.40	0.80	3.1

Tuber quality

Tuber greening incidence was low (4 %) and unaffected by any treatment (Table 4). Similarly, there was no effect of tramline management or irrigation method on internal defects and secondary growth (Table 4). Tubers were fried at the beginning of December after a short storage period and were universally pale (0 or 00 on USDA scale). There was also no effect of tramline management or irrigation method on fry colour (Table 4).

Table 4. Effect of irrigation method and tramline management on tuber greening, Brown Centre, Hollow Heart and fry colour at final harvest. S.E. based on 20 D.F., except for Irrigation main effect, where 2 D.F.

Irrig	Tramline managemt	Greening (%)	Brown Centre (%)	Hollow Heart (%)	Secondary growth (%)	Fry colour (-1 = USDA00)
Boom	CT	5.0	1.7	5.0	11.7	-0.23
	TR	3.3	16.7	15.0	11.7	-0.07
	WTR	5.0	8.3	1.7	10.0	-0.12
	WW	3.3	6.7	3.3	3.3	-0.17
	T	5.0	6.7	11.7	8.3	-0.18
	WWT	5.0	3.3	10.0	5.0	-0.20
Gun	CT	3.3	3.3	3.3	0.0	-0.20
	TR	3.3	8.3	1.7	6.7	-0.15
	WTR	3.3	3.3	0.0	6.7	-0.17
	WW	1.7	6.7	10.0	10.0	-0.17
	T	1.7	6.7	11.7	11.7	-0.23
	WWT	6.7	6.7	5.0	3.3	-0.15
S.E.			3.79	4.27	3.79	0.049
S.E. (same irrig.			3.68	4.61	3.07	0.044
Boom		4.4	7.2	7.8	8.3	-0.16
Gun		3.3	5.8	5.3	6.4	-0.18
S.E.		1.11	1.75	0.68	2.55	0.028
	CT	4.2	2.5	4.2	5.8	-0.22
	TR	3.3	12.5	8.3	9.2	-0.11
	WTR	4.2	5.8	0.8	8.3	-0.14
	WW	2.5	6.7	6.7	6.7	-0.17
	T	3.3	6.7	11.7	10.0	-0.21
	WWT	5.8	5.0	7.5	4.2	-0.18
S.E.		1.23	2.60	3.26	2.17	0.031

Diffuse pollution

Soil properties

C, TR and WW treatments had significantly higher BD values as compared to the WWT and T treatments (Table 5). It is expected that the trafficked treatments would have a higher BD as a result of the additional vehicle passes. The WW treatment had a significantly lower moisture content as compared to all other treatments. C, TR and WTR treatments had significantly lower moisture contents (0-5 cm) as compared to the WWT and T treatments (Table 5). No significant differences were observed between PR values (Table 5).

Table 5. Variability in physical soil characteristics between treatments.

Treatment	Bulk density (BD) 0-5 cm (g cm^{-3})	Moisture content 0-5cm (%)	Penetrative resistance (MPa)		
			Median	Maximum	Minimum
Tied ridger (TR)	1.30a	15.38a	2.21a	2.88a	1.44a
Wheel track roller (WTR)	1.33ab	15.25a	2.38a	2.93a	1.34a
Wonder wheel (WW)	1.30a	14.32c	2.41a	3.05a	1.66a
Control (C)	1.28a	15.06a	2.35a	3.05a	1.48a
Wonder wheel trafficked (WWT)	1.37bc	16.66b	2.58a	2.93a	1.87a
Trafficked (T)	1.40c	16.62b	2.72a	3.24a	1.96a

Note: Within each column, values followed by the same letter are not significantly different ($p<0.05$) following One-Way ANOVA and *post hoc* Fisher LSD analysis.

Treatment performance across sampling events

Treatment performance was evaluated over six sampling events. Due to the low runoff volumes generated by rainfall associated with the Sampling Event 3 period (Table 6), only runoff volume was measured and no runoff samples were taken. Rainfall and irrigation characteristics of each Sampling Event differed (Table 6). Rainfall distribution within each Sampling Event also varied (Figure 12) with Sampling Event 4 having the greatest number of dry days and Sampling Event 5 the greatest number of consecutive days with rainfall (17 days).

Due to contractual delays and time taken to install the runoff and erosion plots the potato canopy was at 100 % ground cover by Sampling Event 1 (Table 6). This meant that the most vulnerable period for runoff and erosion immediately post planting and prior to 50% canopy was missed. Sampling Event 5 and 6 was associated with significantly less than 100 % ground cover as the crop had been sprayed with a desiccant on the 18th and 25th September (Figure 13).

Table 6. Summary of sampling period, rainfall, and irrigation associated with Sampling Events 1-6.

Sampling Event	Collection Period	No. days	Rainfall received (mm)	Irrigation applied (mm)	Ground cover (%)
1	26th – 30th Jun	5	50.8	15	100
2	1st – 13th Jul	13	27.2	30	100
3	14th – 26th Jul	13	27	0	100
4	27th Jul – 30th Aug	35	69.4	30	100
5	31st Aug – 25th Sep	26	48.8	15	<100
6	26th Sep – 9th Oct	14	13.6	0	Minimal

Note: 15 mm of irrigation water was applied where appropriate following a pre-planned schedule.

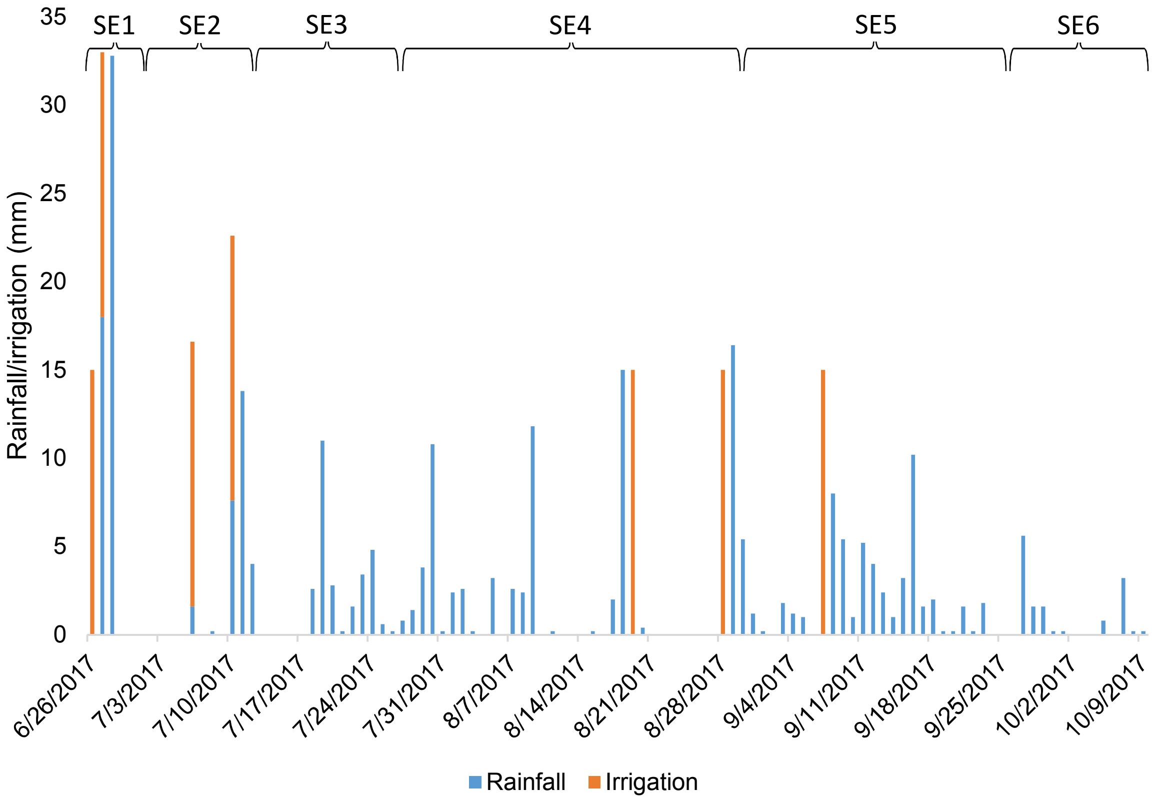


Figure 12. Rainfall and irrigation distribution across all sampling events.

Figure 13. Extent of canopy cover at Sampling Event 5, 25th September 2017.

Runoff volume

Across all sampling periods, the T (Trafficked) treatment generated 80 to 92 % ($p < 0.05$) greater runoff volume as compared to all other treatments across both boom and gun irrigation (Figure 14).

Further, across all Sampling Events and treatments, there was a trend for greater total cumulative runoff volume from boom irrigated treatments (165 l +/-21.4 S.E) as compared with gun irrigated treatments (131 l +/-21.4 S.E.).

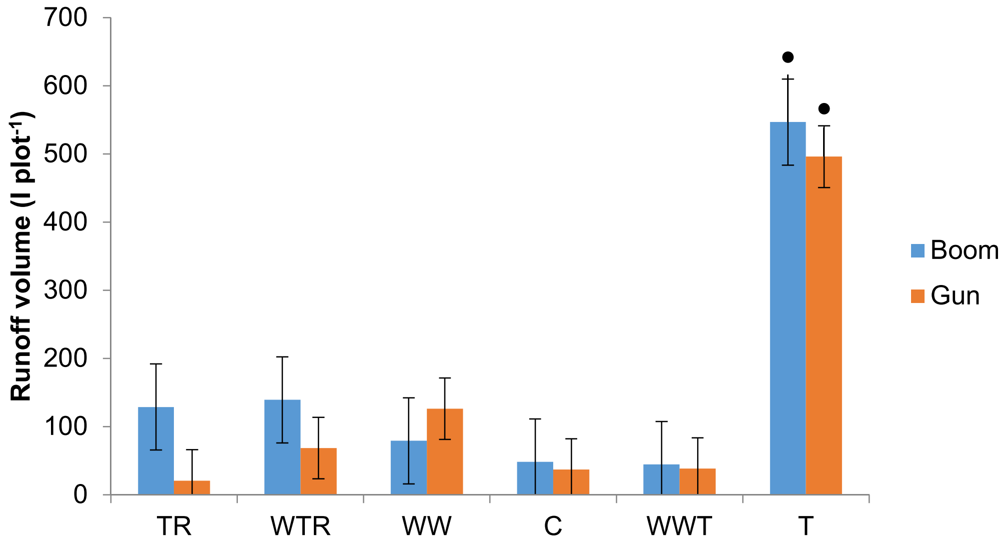


Figure 14. Total cumulative runoff volume across all Sampling Events. Filled circles denote a significant difference between treatments within a specific irrigation type.

Across individual sampling events (Figure 15), the T treatment irrespective of irrigation method generated significantly higher runoff in Sampling Events 1, 2, 4 and 5 respectively as compared to the C treatment. Only in Sampling Events 2 and 4 were significant differences in treatment effect for a specific irrigation method observed. In Sampling Event 2, the T treatment significantly increased runoff volume by > 87 % with gun irrigation as compared to all other gun irrigated treatments. Whilst in Sampling Event 4, both gun and boom irrigated T treatments were associated with a significant increase in runoff volume of > 78 and 84 % respectively as compared to all other treatments.

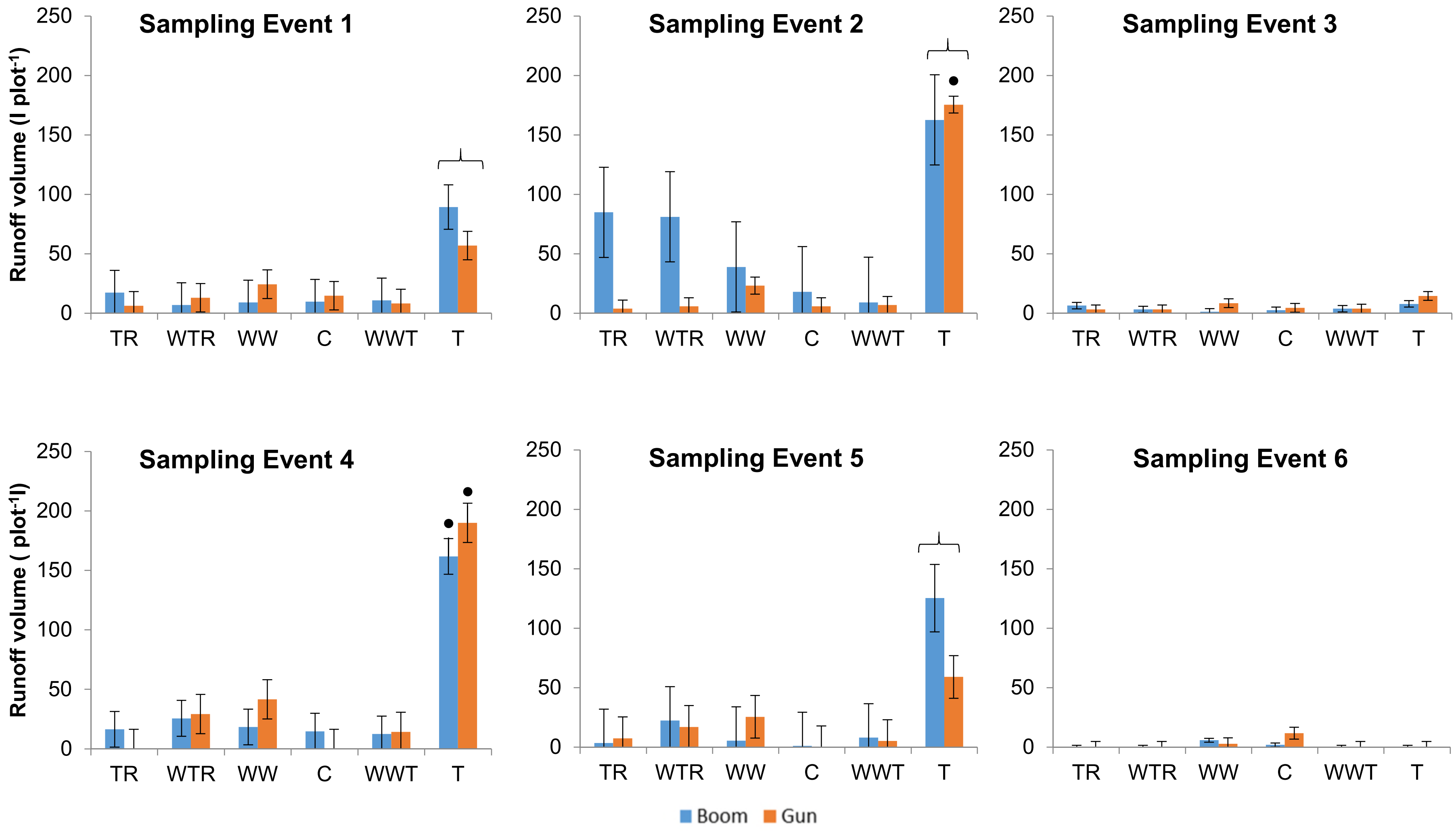


Figure 15. Differences in runoff volume (n=3) between treatments for each Sampling Event. Tied ridger (TR), Wheel Track Roller (WTR), Wonder Wheel (WW), Control (C), Wonder Wheel on trafficked (WWT) and Trafficked (T). Filled circles denote significant differences within treatment for the specified irrigation method. A brace denotes a significant difference in treatment irrespective of irrigation method.

Total soil loss

Across all sampling events, the T treatment generated significantly higher (97 %) total soil loss (TSL) as compared to the C treatment (Figure 16) and all wheeling management treatments (TR, WTR, WW and WWT). Further, no significant differences were observed between the wheeling management treatments (TR, WTR, WW and WWT) and the C treatment. The T treatment generated 93 % and 94 % greater ($p < 0.05$) TSL with gun and boom irrigation respectively, as compared to the C treatment and >90 % greater TSL as compared with the wheeling management treatments (TR, WTR, WW and WWT) (Figure 16).

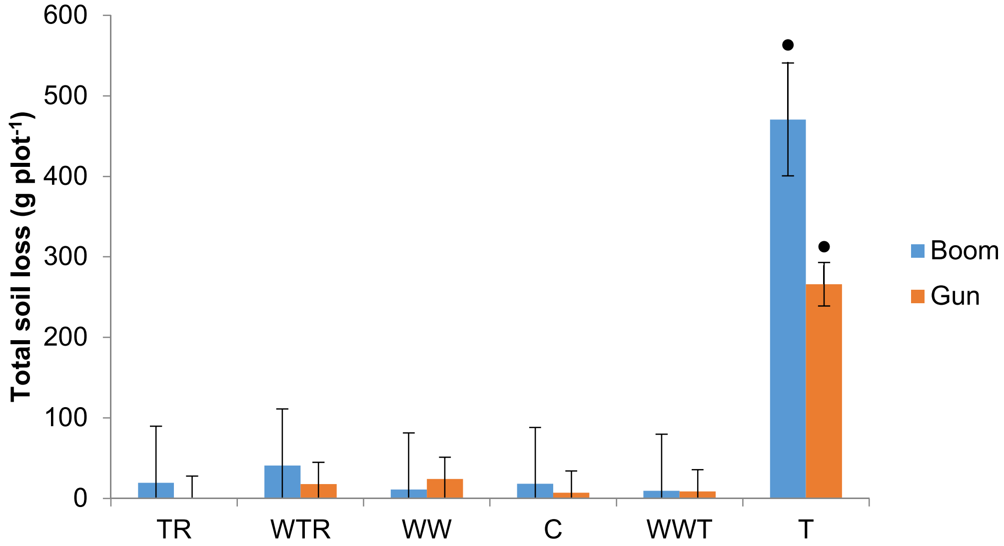


Figure 16. Total cumulative soil loss across all sampling events. Filled circles denote a significant difference between treatments within a specific irrigation type.

Boom irrigated treatments were associated with a significant 43 % increase in TSL across all Sampling Events combined as compared with gun irrigation (Figure 16). This significant difference was also observed on an individual Sampling Event basis with boom irrigation associated with significantly increased TSL (68 %) as compared with gun irrigation for Sampling Event 2 (Figure 17). This suggests that boom irrigation is more erosive than rain guns resulting in increased soil detachment and greater soil loss.

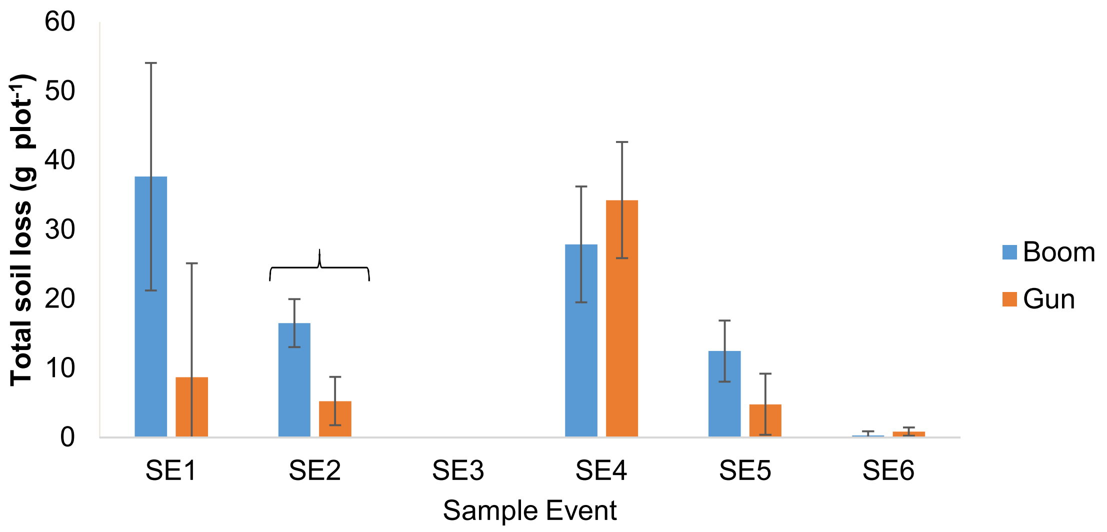


Figure 17. Mean TSL based on irrigation method for each sampling event. A bracket denotes a significant difference in irrigation method irrespective of treatment.

From the TSL results across all sampling events an extrapolation can be made to generate a TSL rate for the sampling period. This extrapolation has been calculated using the following equation:

$$TSL_{rate}\ (kg\ ha^{-1}) = (10{,}000\ m^2\ /\ Plot\ area\ (m^2))\ x\ Treatment\ TSL\ (kg\ plot^{-1})$$

Note: Plot area = 30 x 1.83 m. Treatment TSL results must first be converted from g $plot^{-1}$ to kg $plot^{-1}$.

Treatment TSL_{rate} ranged between 0.0001 t ha^{-1} and 0.08 t ha^{-1} (Table 7). TSL_{rate} values (Table 7) are relatively low as compared to previous potato crop studies, and can be classed as sustainable in the context of the annual rate of soil regeneration, estimated at 1.4 t ha^{-1} (Verheijen et al, 2009).

Table 7. TSL_{rate} (kg ha^{-1} and t ha^{-1}) for each treatment over the entire sampling period across both irrigation treatments (26th June to 9th October, 105 days).

Treatment	Boom irrigation TSL		Gun irrigation TSL	
	(kg ha^{-1})	(t ha^{-1})	(kg ha^{-1})	(t ha^{-1})
TR	3.53	0.0035	0.09	0.0001
WTR	7.44	0.0074	3.23	0.0032
WW	2.02	0.0020	4.38	0.0044
C	3.28	0.0033	1.28	0.0013
WWT	1.73	0.0017	1.54	0.0015
T	85.7	0.0857	48.5	0.0485
Total	103.7	0.1037	58.9	0.0589

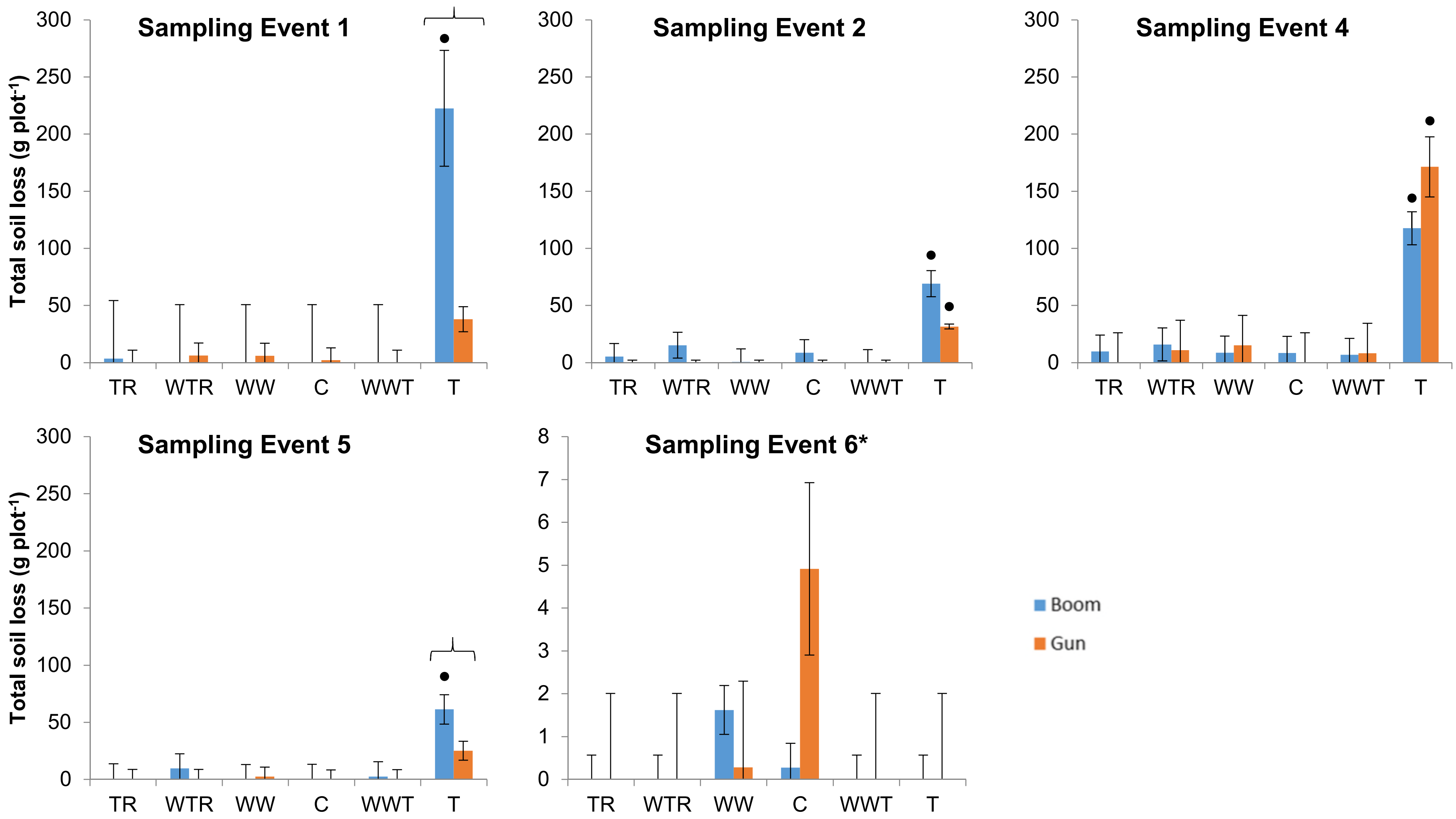


Figure 18. Differences in total soil loss (TSL) (n=3) between treatments for each Sampling Event. Tied ridger (TR), Wheel Track Roller (WTR), Wonder Wheel (WW), Control (C), Wonder Wheel on trafficked (WWT) and Trafficked (T). Filled circles denote a significant difference within treatment for a specified irrigation method. A bracket denotes a significant difference in treatment irrespective of irrigation method. *Note differences in scale for Sampling Event 6.

The observed low erosion rates are primarily associated with the 100% canopy cover in combination with the relatively shallow slope found onsite. Further, these calculated values cannot be considered as representative of the full potato growing season as data collection only began from 100 % cover. This excluded high vulnerability periods e.g. post-bed forming and pre 50% canopy cover.

Caution must be taken when extrapolating from plot to field scale as they assume erosion processes are uniform irrespective of changes in field properties including slope and soil type.

In Sampling Events 1, 2, 4 and 5 the T treatment generated significantly higher TSL as compared to all other treatments, irrespective of irrigation method (Figure 18). Differences between irrigation method were only observed in Sampling Event 1 and 5 when boom irrigated treatments generated significantly more TSL from the T treatment as compared to all other treatments (Figure 18).

Runoff sediment concentrations

Sediment concentration in runoff ranged between 0.006 and 2.5 g l^{-1} (Figure 19). Across all runoff measurements, 27 % exceeded a concentration of 0.25 g l^{-1}, a level that if observed in a watercourse would prompt an investigation by the Environment Agency, and potentially result in financial penalties. These exceedances primarily occurred during Sampling Event 4, in trafficked treatments with boom irrigation (Figure 19).

Significant differences in sediment concentration between treatments were only observed in Sampling Events 1, 2 and 6 (Figure 19). In Sampling Event 1, the boom irrigated T treatment resulted in a significant 100 % increase in sediment concentration as compared with the boom irrigated C treatment with values of 2.5 and 0.25 g l^{-1}, respectively.

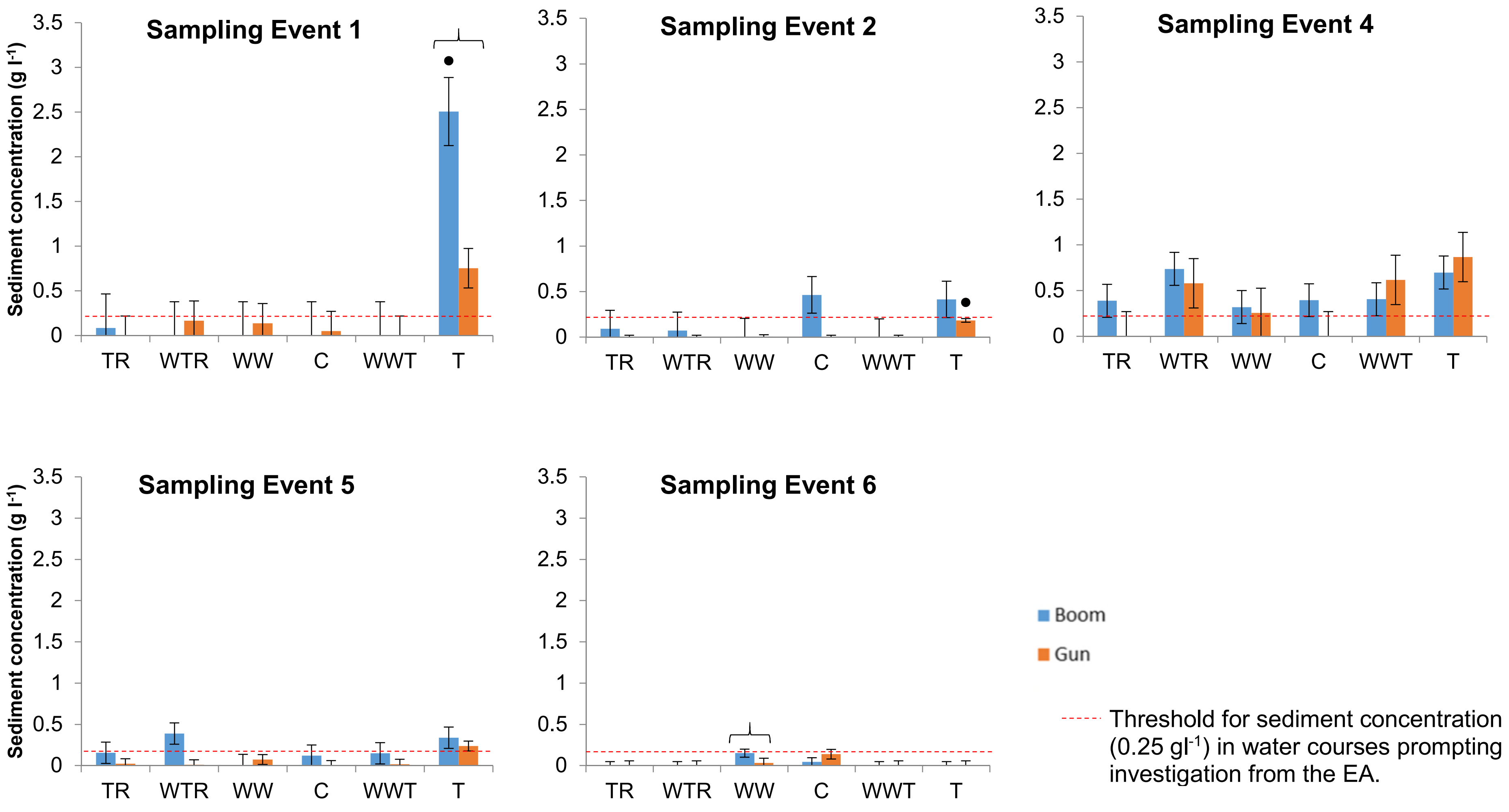


Figure 19. Differences in mean (n=3) runoff sediment concentration (g l^{-1}) between treatments for all Sampling Events. Tied ridger (TR), Wheel Track Roller (WTR), Wonder Wheel (WW), Control (C), Wonder Wheel on trafficked (WWT) and Trafficked (T). Filled circles denote a significant difference within treatment for a specific irrigation method. A brace denotes a significant difference in treatment irrespective of irrigation method.

In contrast, in Sampling Event 2, the gun irrigated T treatment resulted in a significant 100 % increase in sediment concentration as compared with the gun irrigated C treatment with values of 0.2 and 0.02 g l^{-1}, respectively. In Sampling Event 6, only the WW and C treatments generated runoff with sediment concentrations significantly greater than all other treatments irrespective of irrigation method (Figure 19).

Although robust trends were observed in Sampling Events 1 and 2, significant differences in runoff sediment concentration between boom and gun irrigation were only observed in Sampling Event 5 where boom irrigation resulted in a significant 69 % increase in sediment concentration as compared with gun irrigation (Figure 20).

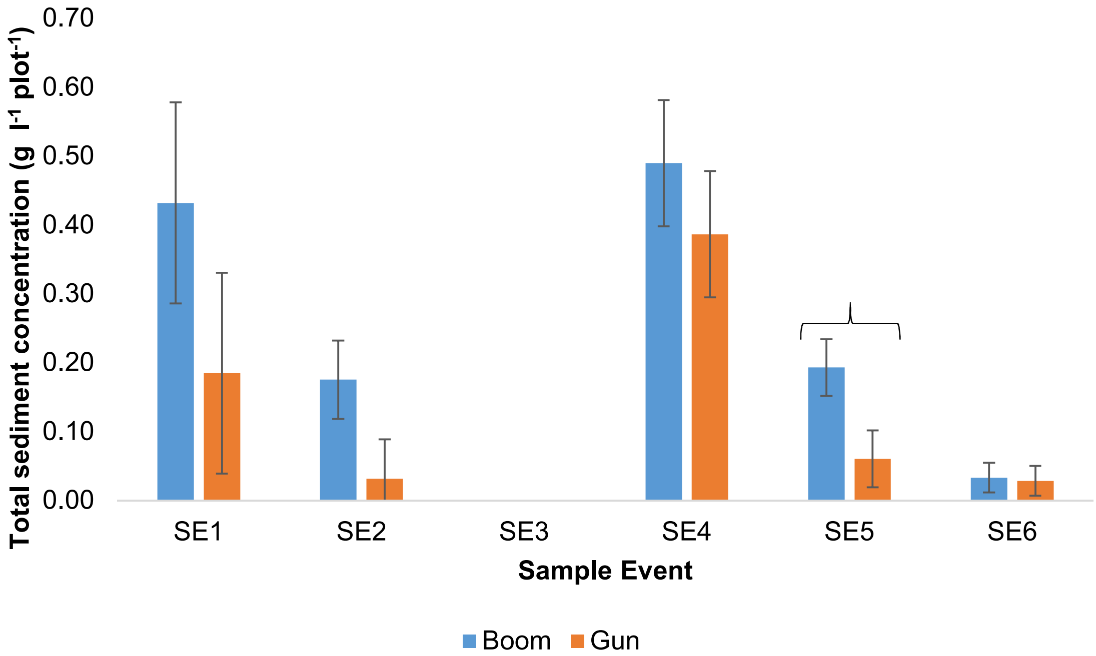


Figure 20. Mean total cumulative sediment concentration based on irrigation method for each sampling event. A bracket denotes a significant difference in irrigation method irrespective of treatment.

Runoff Total oxides of Nitrogen (TON) concentrations

Across all treatments and Sampling Events irrespective of irrigation method, TON concentration did not exceed the 50 mg l^{-1} limit prescribed for water quality of water bodies by the EC Nitrates Directive (91 / 676 /EEC) (Figure 22).

The highest TON concentrations were observed in Sampling Event 4 (Figure 22). The period between Sampling Event 3 and 4 was associated with the application (24th July 2017) of 20.1 kg N ha^{-1} as a granular ammonium nitrate fertiliser (Figure 21). The T treatment irrespective of irrigation method was associated with significantly increased runoff TON concentration in Sampling Event 1 and 2 as compared to all other treatments (Figure 22). In contrast, the boom irrigated WTR treatment was associated with significantly increased runoff TON concentration as compared to all other treatments in Sampling Event 5.

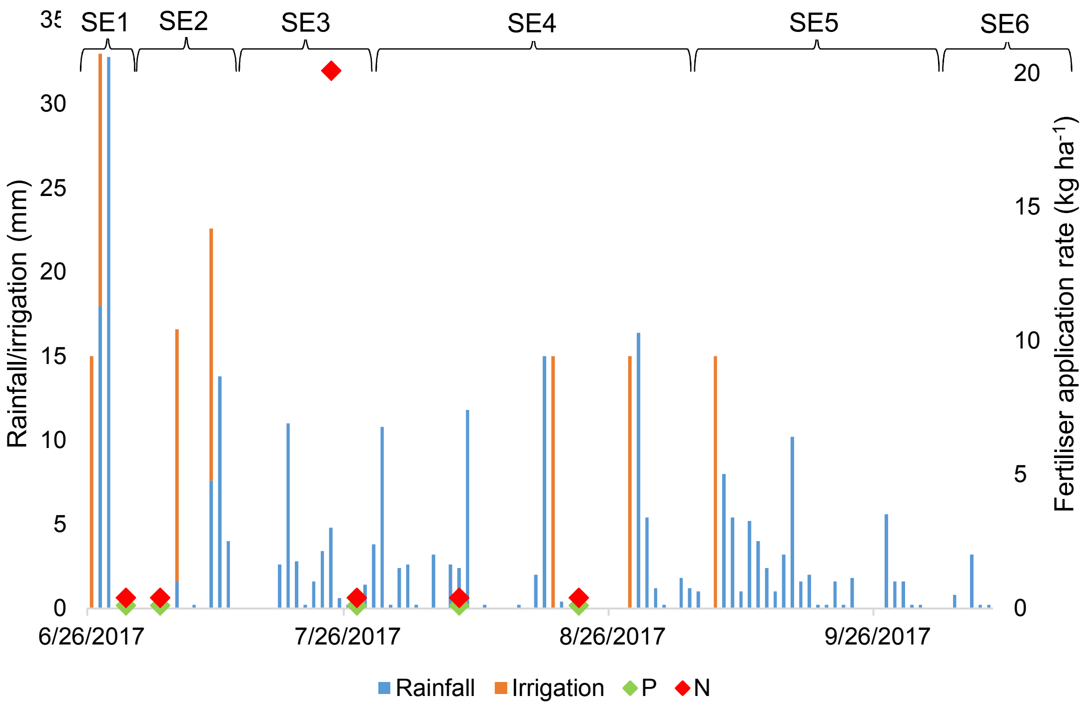


Figure 21. N and P application rates (kg ha^{-1}) within each Sampling Period relative to received rainfall and applied irrigation.

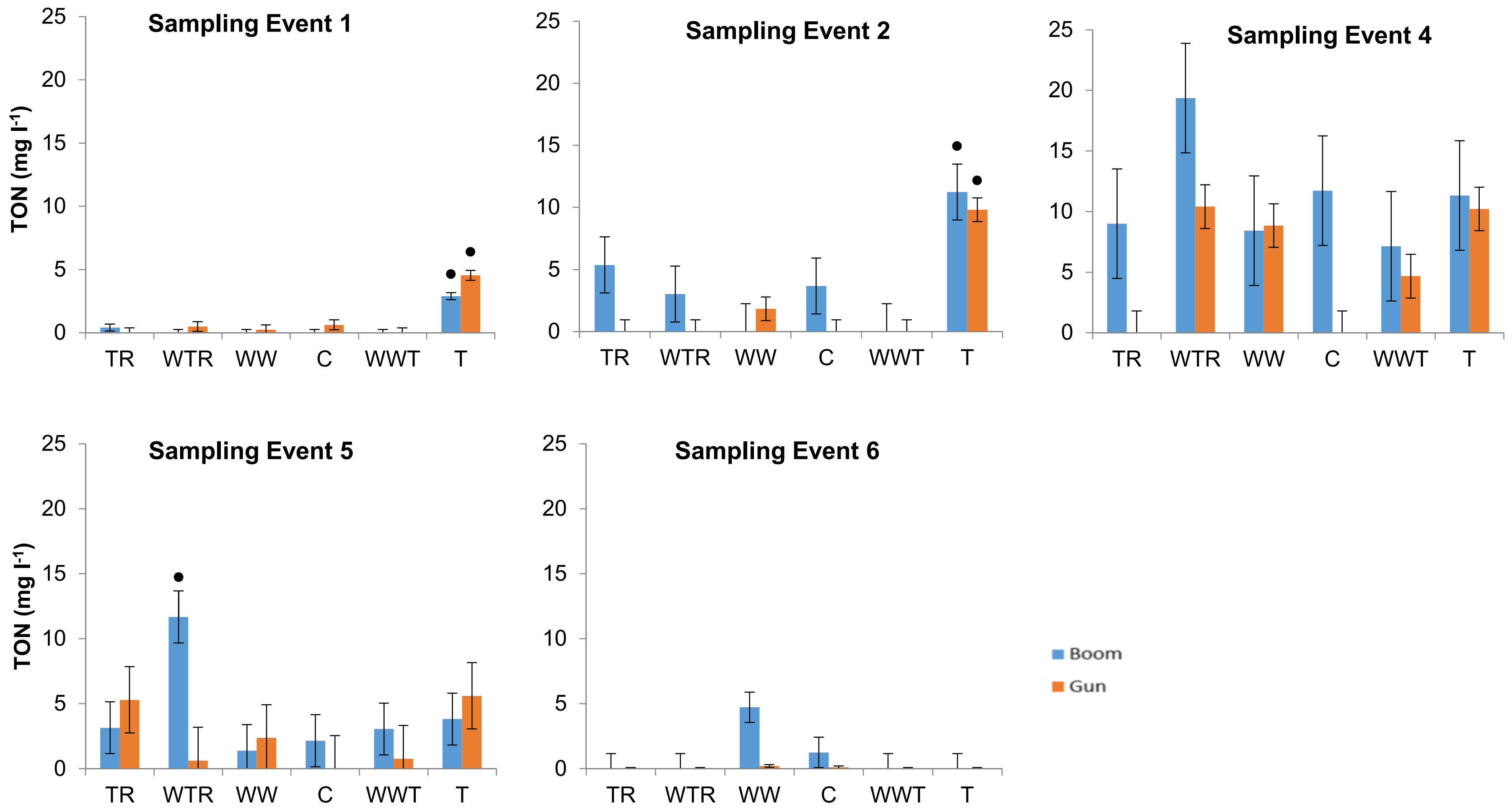


Figure 22. Differences in mean (n=3) runoff TON concentration between treatments across Sampling Events. Tied ridger (TR), Wheel Track Roller (WTR), Wonder Wheel (WW), Control (C), Wonder Wheel on trafficked (WWT) and Trafficked (T). Filled circles denote a significant difference within treatment for a specific irrigation method. Error bars represent ± 1 S.E.

Significant differences between boom and gun irrigation irrespective of treatment were only observed in Sampling Event 4, where boom irrigation increased TON by 49 % as compared to gun irrigation (Figure 23).

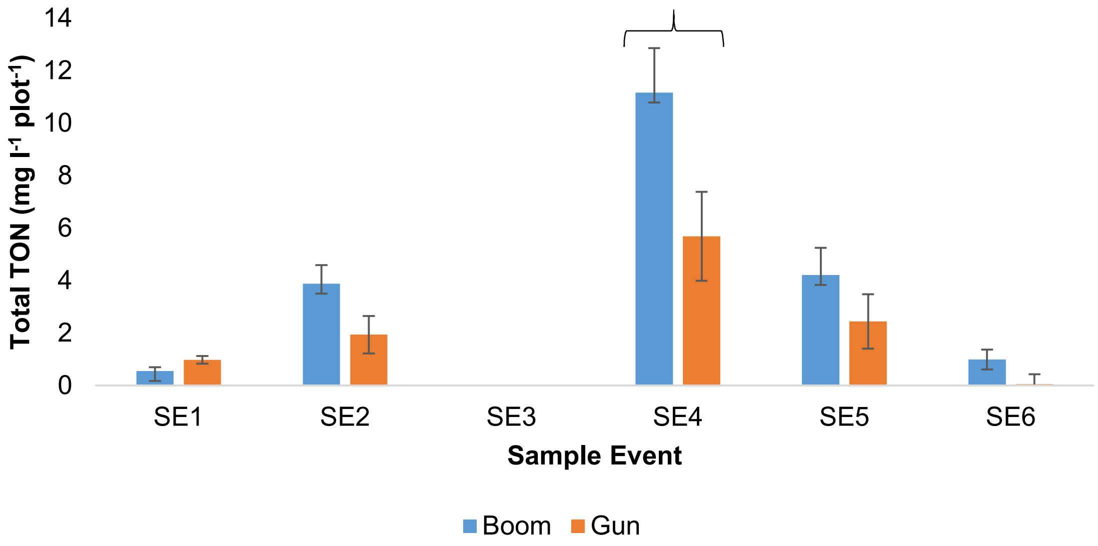


Figure 23. Mean total TON based on irrigation method for each sampling event. A brace denotes a significant difference in irrigation method irrespective of treatment.

Runoff Orthophosphate concentrations

As with TON, the greatest orthophosphate concentration was observed in Sampling Event 4. This is again likely due to the greatest number of P applications during the Sampling Period 3 to 4 as well as rainfall (Figure 21).

In 50 % of runoff samples irrespective of Sampling Event and irrigation method, orthophosphate-P concentrations exceeded 0.1 mg l^{-1}, a concentration at which P begins to have an eutrophication effect on water quality (Defra, 2012). For the T treatment, 27 % of runoff samples were associated with orthophosphate-P concentrations exceeding the 0.1 mg l^{-1} limit (Figure 24). For the WW, C, TR, WTR and WWT treatments 23, 17, 13, 10 and 10 % of runoff samples were associated with orthophosphate-P concentrations exceeding the 0.1 mg l^{-1} limit, respectively (Figure 24). Across all Sampling Events, boom irrigated treatments were responsible for 60 % of these exceedances.

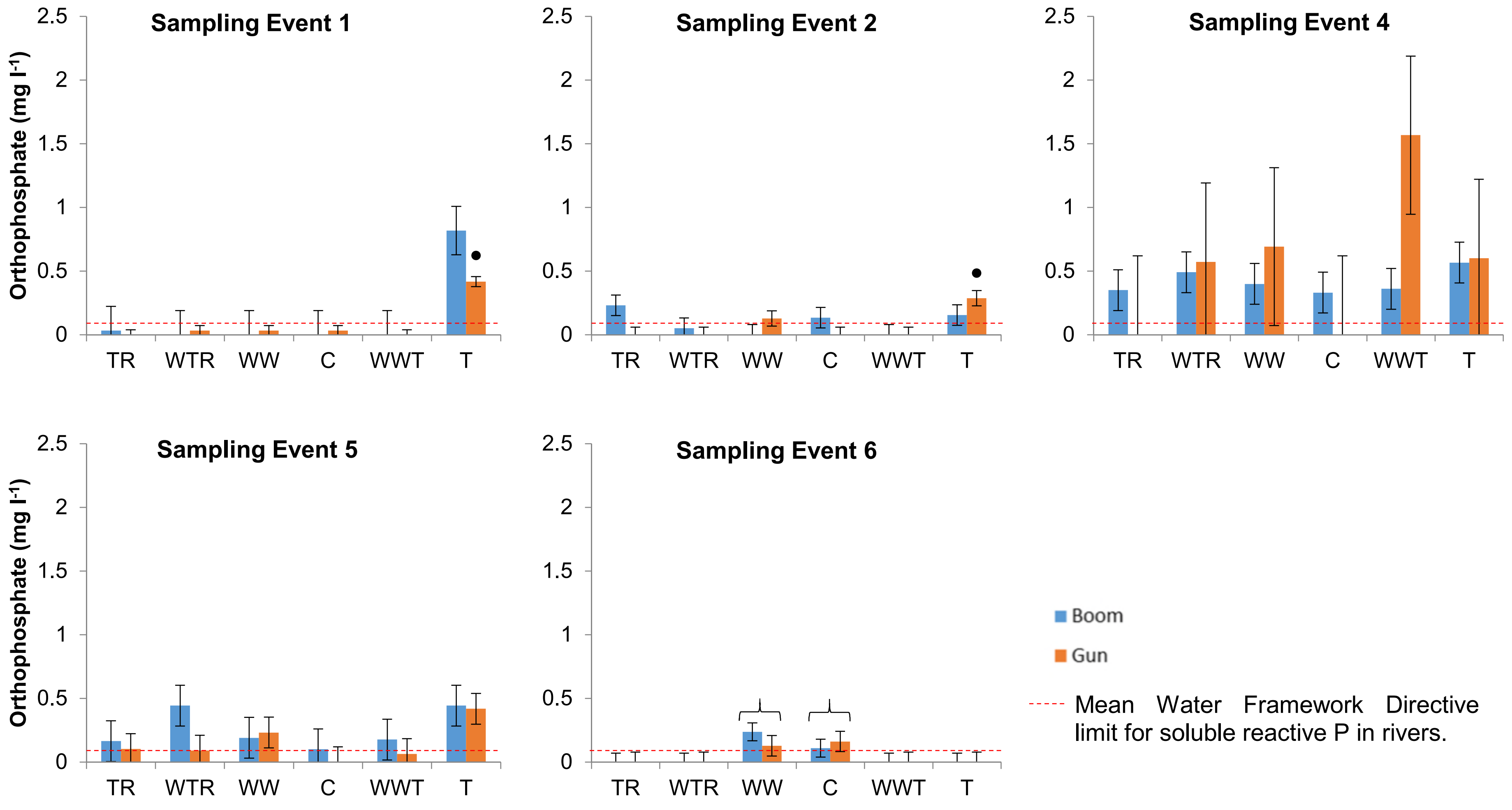


Figure 24. Differences in mean (n=3) orthophosphate concentration in runoff across all Sampling Events. Tied ridger (TR), Wheel Track Roller (WTR), Wonder Wheel (WW), Control (C), Wonder Wheel on trafficked (WWT) and Trafficked (T). Filled circles denote a significant difference within treatment for a specific irrigation method. A brace denotes a significant difference in treatment irrespective of irrigation method.

Conclusions

The T (Trafficked) treatment generated significantly higher runoff volume, runoff total soil loss, sediment and TON concentrations as compared to all other treatments. In comparison, the post trafficking disturbance with the Bye Engineering Wonder Wheel, (WWT) reduced diffuse pollution to such an extent that results did not significantly differ from the C, WW, TR and WTR treatments. The Bye Engineering Wonder Wheel was the only tramline disruption method tested on trafficked plots. Therefore the efficacy of other wheeling disruption treatments post trafficking could not be assessed. No significant differences were observed between post-planting treatments (WW, TR and WTR) and the Control. Despite 100 % canopy cover, potentially polluting events in terms of sediment concentration and orthophosphate were observed from all treatments in at least one sampling event. Boom irrigated treatments resulted in some significant differences in total soil loss and runoff sediment and TON concentrations as compared to gun irrigated treatments. Care must be taken when applying these results to other fields as they represent growing conditions on one soil type a shallow slope under climatically dry conditions with a favourable canopy cover. Despite differences in run off volume and sediment movement between different tramline treatments, there were no effects on yield, tuber quality (including greening) or fry colour. There was an indication that secondary-trafficked rows without Wonder Wheel amelioration had numerically lower yield than the other tramline management regime.

Recommendations

- Further research is required to fully evaluate the efficacy of the treatments tested for a range of soil types, slopes, potato varieties (and associated bed-forms) across the entire cropping cycle from pre-emergence to harvest. Such research will significantly increase the confidence of recommendations to adopt wheeling disruption as a best management practice for prevent erosion and diffuse pollution control as well as increase water use efficiency in potato production.
- Further research is required to investigate the drop size distributions, impact velocities and kinetic energy associated with boom-irrigation nozzles across a range of application rates such that ‘erosivity’ of boom irrigation can be reduced without compromising irrigation efficiency and uniformity. This is of particular relevance during scab control periods when plant canopy is not fully developed.

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