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The MPI SFF root zone reality project (401484) and the HortNZ northern fluxmeters project (HortNZ RI 1009) – summary of year 1 and year 2 activity

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EXECUTIVE SUMMARY

The MPI SFF root zone reality project (401484) and the HortNZ northern fluxmeters project (HortNZ RI 1009) – summary of year 1 and year 2 activity

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In July 2014 two projects were commissioned to establish a network of passive-wick tension fluxmeters in commercial cropping farms in Canterbury, Manawatu, Hawke's Bay and Matamata/Pukekohe. The fluxmeter network is being used to measure nutrient concentrations of nitrogen (N) and phosphorus (P) in drainage water under good management practices.

This report summarises activity for the period between fluxmeter installation (August 2014 to May 2015) and 30 October 2016.

The experimental design across the network includes four monitor regions, three sites per region and 12 fluxmeters per site. The fluxmeters were installed to collect drainage at a depth of 1 m, selected to represent a depth below which nutrient uptake across most crop species is likely to be minimal. Sites provide a range of cropping systems, soil types, climatic conditions and management practices relevant to each region.

A range of soil, plant and leachate measurements are being collected from the sites on an ongoing basis and key results are summarised below. Respective soil fertility ranges considered as 'low', 'moderate' or 'high' are listed as follows: for mineral N, 0–50, 50–150 and > 150 kg N/ha, for anaerobically mineralisable nitrogen (AMN), 0–100, 100–200 and > 200 kg N/ha and for Olsen P, 0–20, 20–50 and > 50 mg P/L.

Site 1 — Canterbury

Site 1 is located on a Mayfield silt loam. Fluxmeters were installed in August 2014 into an established ryegrass seed crop. The crop was harvested for seed in January 2015 and subsequently grazed in July 2015. Spring wheat was sown in August 2015 and harvested in March 2016 and the site sown with barley (the current crop) in April 2016.

Rainfall for the Year 1 monitoring period (1 October 2014 to 30 September 2015) totalled 416 mm, 44% below the long-term average for the area (748 mm). The amount of irrigation applied over this period totalled 268 mm. There were six drainage samplings with a total drainage volume of 101 mm. Most (89%) drainage was collected between July and September 2015. Mineral N and total P losses in drainage were 43 kg N/ha and 0.15 kg P/ha respectively.

Rainfall for the Year 2 monitoring period (1 October 2015 to 30 September 2016) totalled 536 mm, 28% below the long-term average for the area. The amount of irrigation applied over this period totalled 207 mm. There were nine drainage samplings with a total drainage volume of 74 mm. About half (52%) of the drainage was collected between early June and mid-August 2016. Mineral N and total P losses in drainage were 44 kg N/ha and < 0.05 kg P/ha respectively. Residual soil mineral N concentrations (0–100 cm depth) at the most recent sampling occasion

in April 2015 were high (239 kg N/ha) while Olsen P concentrations (0–20 cm depth) were low (12 mg/L).

Site 2 — Canterbury

Site 2 is located near Methven on a mixed cropping and livestock grazing enterprise. Soil type is a Barrhill silt loam. Since installation of the fluxmeters in September 2014 there have been three crops including barley planted in October 2014, white clover planted in March 2015 and a second barley crop planted in September 2016. The second barley crop was sown to provide early cover for a carrot crop which is due to be planted in mid-October.

Rainfall for the Year 1 monitoring period (1 October 2014 to 30 September 2015) totalled 565 mm, 24% below the long-term average for the area (748 mm). The amount of irrigation applied over this period totalled 145 mm. There were three drainage samplings with a total drainage volume of 13 mm. All drainage was collected between July and September 2015. Mineral N and total P losses in drainage totalled 3 kg N/ha and 0.09 kg P/ha respectively.

Rainfall for the Year 2 monitoring period (1 October 2015 to 30 September 2016) totalled 484 mm, 35% below the long-term average for the area. The amount of irrigation applied over this period totalled 60 mm. There was only one sampling event (November 2015) with a total drainage volume of only 1 mm. Due to low drainage volumes, mineral N and total P losses were very low (< 0.5 kg N/ha and < 0.05 kg P/ha). Residual mineral N concentrations (0–100 cm depth) at the most recent sampling occasion in August 2016 were high (244 kg N/ha) while Olsen P concentrations (0–20 cm depth) were low (16 mg/L).

Site 3 — Canterbury

Site 3 is located near Southbridge on a mixed cropping and livestock grazing farm. Soil type is a Templeton silt loam. Fluxmeters were installed in September 2014 into an established ryegrass seed crop. The ryegrass seed crop was harvested in January 2015 and the site rotationally grazed until early November 2015 before being sown with process beans in December 2015. The beans were harvested in March 2016 and the site subsequently sown with forage oats (the current crop).

Rainfall for the Year 1 monitoring period (1 October 2014 to 30 September 2015) totalled 547 mm, 11% below the long-term average for the region (616 mm). The amount of irrigation applied over this period totalled 450 mm. There were two drainage samplings with a total drainage volume of 8 mm. All drainage was collected between August and September 2015. Due to low drainage volumes, mineral N and tot P losses were low (1 kg N/ha and < 0.05 kg P/ha).

Rainfall for the Year 2 monitoring period (1 October 2015 to 30 September 2016) totalled 442 mm, 28% below the long-term average for the area. The amount of irrigation applied over this period totalled 270 mm. There were four drainage samplings with a total drainage volume of 39 mm. Over half (63%) of the drainage was collected in February 2016. Mineral N and total P losses in drainage totalled 4 kg N/ha and 0.07 kg P/ha respectively. Residual soil mineral N concentrations (0–100 cm depth) at the most recent sampling occasion in April 2016 were high (321 kg N/ha) while Olsen P concentrations (0–20 cm depth) were moderate (25 mg/L).

Site 4 — Manawatu

Site 4 is located near Levin on an intensive vegetable cropping enterprise. Soil type is a Shannon silt loam. Since installation of the fluxmeters in October 2014 there have been five crop sequences including lettuce planted in October 2014, two spinach cycles planted in February and May 2015, lettuce planted in January 2016 and cabbage planted in March 2016. Zucchini is due to be planted in mid-October.

Rainfall for the Year 1 monitoring period (1 October 2014 to 30 September 2015) totalled 1046 mm, 5% higher than the long-term average for the area (995 mm). The amount of irrigation applied over this period totalled 22 mm. There were eight drainage samplings with a total drainage volume of 339 mm. Most (81%) of the drainage was collected between April and September 2015. Mineral N and total P losses in drainage totalled 212 kg N/ha and 0.56 kg P/ha respectively.

Rainfall for the Year 2 monitoring period (1 October 2015 to 30 September 2016) totalled 1018 mm, 1% higher than the long-term average for the area. The amount of irrigation applied over this period totalled 40 mm. There were eight drainage samplings with a total drainage volume of 339 mm, the same total volume as was collected over the Year 1 period. Most (72%) of the drainage was collected over the winter to early spring period (June to September). Mineral N and total P losses in drainage totalled 118 kg N/ha and 0.27 kg P/ha respectively. Residual soil mineral N (0–100 cm depth) and Olsen P concentrations (0–20 cm) at the most recent sampling occasion in March 2016 were high (154 kg N/ha and 122 mg/L respectively).

Site 5 — Manawatu

Site 5 is located near Bulls on a mixed cropping and livestock grazing enterprise. Soil type is a Pukepuke sandy loam. Since installation of the fluxmeters in September 2014 there have been three crops including maize sown in October 2014, an oats cover crop sown in August 2015 and a fodder beet crop sown in November 2015. The site is currently fallow and due to be planted with forage oats in mid-October 2016.

Rainfall for the Year 1 monitoring period (1 October 2014 to 30 September 2015) totalled 1189 mm, 27% higher than the long-term average for the area (934 mm). The amount of irrigation applied over this period totalled 368 mm. There were seven drainage samplings with a total drainage volume of 611 mm. Most (78%) of the drainage was collected between April and September 2015. Mineral N and total P losses in drainage totalled 226 kg N/ha and 0.49 kg P/ha respectively.

Rainfall for the Year 2 monitoring period (1 October 2015 to 30 September 2016) totalled 933 mm, comparable to the long-term average for the area. The amount of irrigation applied over this period totalled 410 mm. There were ten drainage samplings with a total drainage volume of 411 mm. Drainage was collected at regular intervals during the monitoring period. Mineral N and total P losses in drainage totalled 75 kg N/ha and 0.20 kg P/ha respectively. Residual soil mineral N (0–100 cm depth) concentrations at the most recent sampling occasion in September 2016 were low (44 kg N/ha) while Olsen P concentrations (0–20 cm depth) were moderate (32 mg/L).

Site 6 — Manawatu

Site 6 is located near Ohakune on a mixed cropping enterprise. Soil type is an Ohakune brown loam. Fluxmeters were installed in April 2015 and the site sown with winter wheat in May 2015. Following harvest of the wheat crop in February 2016, the site remained fallow until June 2016 when a second wheat crop was planted (the current crop).

Rainfall for the Year 1 monitoring period (1 October 2014 to 30 September 2015) totalled 1401 mm, 8% higher than the long-term average for the area (1300 mm). No irrigation was applied over this period. There were three drainage samplings with a total drainage volume of 196 mm. All drainage was collected between June and September 2015. Mineral N and total P losses in drainage have totalled 37 kg N/ha and 0.21 kg P/ha respectively.

Rainfall for the Year 2 monitoring period (1 October 2015 to 30 September 2016) totalled 1222 mm, 6% less than the long-term average for the area. No irrigation was applied over this period. There were six drainage samplings with a total drainage volume of 228 mm. Most (90%) of the drainage was captured between mid-June and mid-September 2016. Mineral N and total P losses in drainage totalled 16 kg N/ha and 0.06 kg P/ha respectively. Residual soil mineral N concentrations (0–100 cm depth) at the most recent sampling occasion in June 2016 were high (167 kg N/ha) while Olsen P concentrations (0–20 cm depth) were moderate (26 mg/L).

Site 7 — Hawke's Bay

Site 7 is located near Otane on a mixed cropping and livestock grazing enterprise. Soil type is a Waimakariri silt loam. Since installation of the fluxmeters in September 2014 there have been four crop sequences including a carrot crop sown in September 2014, an Italian ryegrass crop sown in February 2015, a pea crop sown in October 2015 and an Italian ryegrass crop sown in January 2016. The most recent Italian rye grass crop was sprayed off in mid-September 2016 in preparation for sowing of a pea crop in October.

Rainfall for the Year 1 monitoring period (1 October 2014 to 30 September 2015) totalled 661 mm, 14% below the long-term average for the area (765 mm). The amount of irrigation applied over this period totalled 88 mm. There were three drainage samplings with a total drainage volume of 20 mm. Most (90%) of the drainage was collected between November and December 2014. Mineral N and total P losses in drainage totalled 2 kg N/ha and 0.07 kg P/ha respectively.

Rainfall for the Year 2 monitoring period (1 October 2015 to 30 September 2016) totalled 573 mm, 25% below the long-term average for the area. The amount of irrigation applied over this period totalled 140 mm. There were five drainage samplings with a total drainage volume of 21 mm. Most (93%) of the drainage was captured between mid-June and mid-September 2016. All drainage was collected between October and November 2015. Mineral N and total P losses in drainage totalled 2 kg N/ha and 0.06 kg P/ha respectively. Residual soil mineral N concentrations (0–100 cm depth) at the most recent sampling occasion in September 2016 were low (41 kg N/ha) while Olsen P concentrations (0–20 cm depth) were moderate (29 mg/L).

Site 8 — Hawke's Bay

Site 8 is located near Hastings on a mixed cropping and livestock grazing enterprise. Soil type is a Waimakariri silt loam. Since installation of the fluxmeters in October 2014 there have been four crop sequences including a sweetcorn crop sown in December 2014, an Italian ryegrass crop sown in March 2015, a tomato crop sown in October 2015 and an Italian ryegrass crop sown in March 2016. The most recent Italian rye grass crop was sprayed off in mid-September 2016 in preparation for sowing of a sweetcorn crop in October.

Rainfall for the Year 1 monitoring period (1 October 2014 to 30 September 2015) totalled 651 mm, 8% below the long-term average for the area (711 mm). The amount of irrigation applied over this period totalled 76 mm. There was only one drainage sampling in this period (September 2015) with a total drainage volume of 0.3 mm. Due to low drainage volumes, mineral N and total P losses in drainage were very low (< 0.5 kg N/ha and < 0.05 kg P/ha respectively).

Rainfall for the Year 2 monitoring period (1 October 2015 to 30 September 2016) totalled 596 mm, 16% below the long-term average for the area. The amount of irrigation applied over this period totalled 150 mm. There was no drainage recorded over this period and consequently no drainage losses of mineral N or total P. Residual soil mineral N concentrations (0–100 cm depth) at the most recent sampling occasion in October 2016 were low (34 kg N/ha) while Olsen P concentrations (0–20 cm depth) were moderate (40 mg/L).

Site 9 — Hawke's Bay

Site 9 is located near Takapau on a mixed cropping and livestock grazing enterprise. Soil type is a Takapau silt loam. Fluxmeters were installed in September 2014 and the site subsequently sown with peas and then beans. The site remained fallow until August 2015 before being planted with barley which was harvested in January 2016. Italian ryegrass (the current crop) was sown in March 2016 for winter grazing.

Rainfall for the Year 1 monitoring period (1 October 2014 to 30 September 2015) totalled 1035 mm, 7% below the long-term average for the area (1112 mm). The amount of irrigation applied over this period totalled 103 mm. There were eight drainage samplings with a total drainage volume of 62 mm. Most (90%) of the drainage was collected between June and September 2015. Mineral N and total P losses in drainage totalled 7 kg N/ha and < 0.05 kg P/ha respectively.

Rainfall for the Year 2 monitoring period (1 October 2015 to 30 September 2016) totalled 989 mm, 11% below the long-term average for the area. The amount of irrigation applied over this period totalled 150 mm. There were six drainage samplings with a total drainage volume of 66 mm. Over half (65%) of the drainage was collected between mid-August and mid-September 2016. Mineral N and total P losses in drainage totalled 17 kg N/ha and 0.06 kg P/ha respectively. Residual soil mineral N (0–60 cm depth) and Olsen P concentrations (0–20 cm depth) at the most recent sampling occasion in January 2016 were low (58 kg N/ha and 17 mg/L respectively).

Site 10 — Matamata/Pukekohe

Site 10 is located near Matamata on a mixed cropping and livestock grazing enterprise. Soil type is a Waihou silt loam. Fluxmeters were installed in May 2015 and the site subsequently sown with Italian ryegrass which was sprayed off in September 2015. Potatoes were sown in October 2015 and harvested in March 2016. Onions (the current crop) were planted early July 2016.

Rainfall for the Year 1 monitoring period (1 October 2014 to 30 September 2015) totalled 1043 mm, 8% below the long-term average for the area (1131 mm). The amount of irrigation applied over this period totalled 80 mm. There were four drainage samplings with a total drainage volume of 150 mm. All drainage was collected between July and September 2015. Mineral N and total P losses in drainage totalled 30 kg N/ha and 0.06 kg P/ha respectively.

Rainfall for the Year 2 monitoring period (1 October 2015 to 30 September 2016) totalled 1050 mm, 7% below the long-term average for the area. The amount of irrigation applied over this period totalled 120 mm. There were six drainage samplings with a total drainage volume of 112 mm. Most (75%) of the drainage was collected between mid-July and mid-September 2016. Mineral N and total P losses in drainage totalled 12 kg N/ha and < 0.05 kg P/ha respectively. Soil mineral N concentrations (0–100 cm depth) at the most recent sampling occasion in July 2016 were high (346 kg N/ha) while Olsen P concentrations (0–20 cm depth) were moderate (41 mg/L).

Site 11 — Matamata/Pukekohe

Site 11 is located near Pukekohe on an intensive vegetable cropping enterprise. Soil type is a Patumahoe clay loam. Fluxmeters were installed in March 2015 and the site subsequently sown with potatoes in June 2015. The site remained fallow following harvest of the potato crop in November 2015 before being planted with onions (the current crop) in June 2016.

Rainfall for the Year 1 monitoring period (1 October 2014 to 30 September 2015) totalled 1166 mm, 1% less than the long-term average for the area (1183 mm) while rainfall for the Year 2 monitoring period (1 October 2015 to 30 September 2016) totalled 1273 mm, 8% higher than the long-term average for the area. There was no irrigation applied in either year.

Due to periodic flooding of the fluxmeter units in both years an alternative approach is being considered to estimate losses using a combination of measured N and P concentrations and modelled drainage volumes (as is the common approach for measuring losses using devices like suction cups). To ensure a high level of confidence in the predictions, additional soil physical measurements are being collected from the site. These will be used in the soil water balance model to predict drainage volumes. An onsite rain gauge will also be installed to accurately quantify inputs from rainfall and irrigation.

Residual soil mineral N concentrations (0–100 cm depth) at the most recent sampling occasion in July 2016 were moderate (145 kg N/ha) while Olsen P concentrations (0–20 cm depth) were high (148 mg/L).

Site 12 — Matamata/Pukekohe

Site 12 is located near Tuakau on a mixed cropping and livestock grazing enterprise. Soil type is a Patumahoe clay loam. Fluxmeters were installed in April 2015 and the site remained fallow until potatoes were sown in November 2015. The potato crop was harvested in April 2016 and the site has been fallow since.

Rainfall for the Year 1 (1 October 2014 to 30 September 2015) and Year 2 (1 October 2015 to 30 September 2016) monitoring periods totalled 1166 mm and 1273 mm respectively, comparable or slightly higher than the long-term average for the area (1183 mm). During the first year of monitoring, drainage volumes captured in the fluxmeters were considerably higher than those predicted by the soil water balance. The experimental site was subsequently re-established in June 2016 in an area of the field less prone to flooding of the fluxmeter units. Since reinstallation there has been one drainage sample collected in December 2016. While drainage volumes were similar to those predicted by the soil water balance, further sample collection over the coming months is required to confirm the success of the reinstall.

Soil mineral N (0–100 cm depth) and Olsen P concentrations (0–20 cm depth) at the most recent sampling occasion in August 2016 were high (153 kg N/ha and 118 mg/L).

Summary

Across the 12 sites cumulative mineral N losses for the Year 1 monitoring period (1 October 2014 to 30 September 2015) ranged from 0 to 226 kg N/ha. Mineral N losses for the Year 2 monitoring period (1 October 2015 to 30 September 2016) ranged from 0 to 118 kg N/ha (Figure i). High net losses were associated with high drainage volumes and mineral N concentrations (predominantly nitrate-N) in drainage water. In most cases drainage losses occurred during the late autumn, winter and/or early spring months when rainfall and soil moisture levels were highest. At a number of sites soil mineral N concentrations were high even though drainage losses were low. This represents a high risk of loss.

Cumulative P losses in the respective Year 1 and Year 2 monitoring periods ranged from 0 to 0.56 kg P/ha and from 0 to 0.27 kg P/ha (Figure i). These represented fairly small net losses, of which the majority (50–95%) was in the dissolved reactive form (DRP) in the drainage water. At some sites soil Olsen P concentrations were very high, well above recommended sufficiency concentrations for crops.

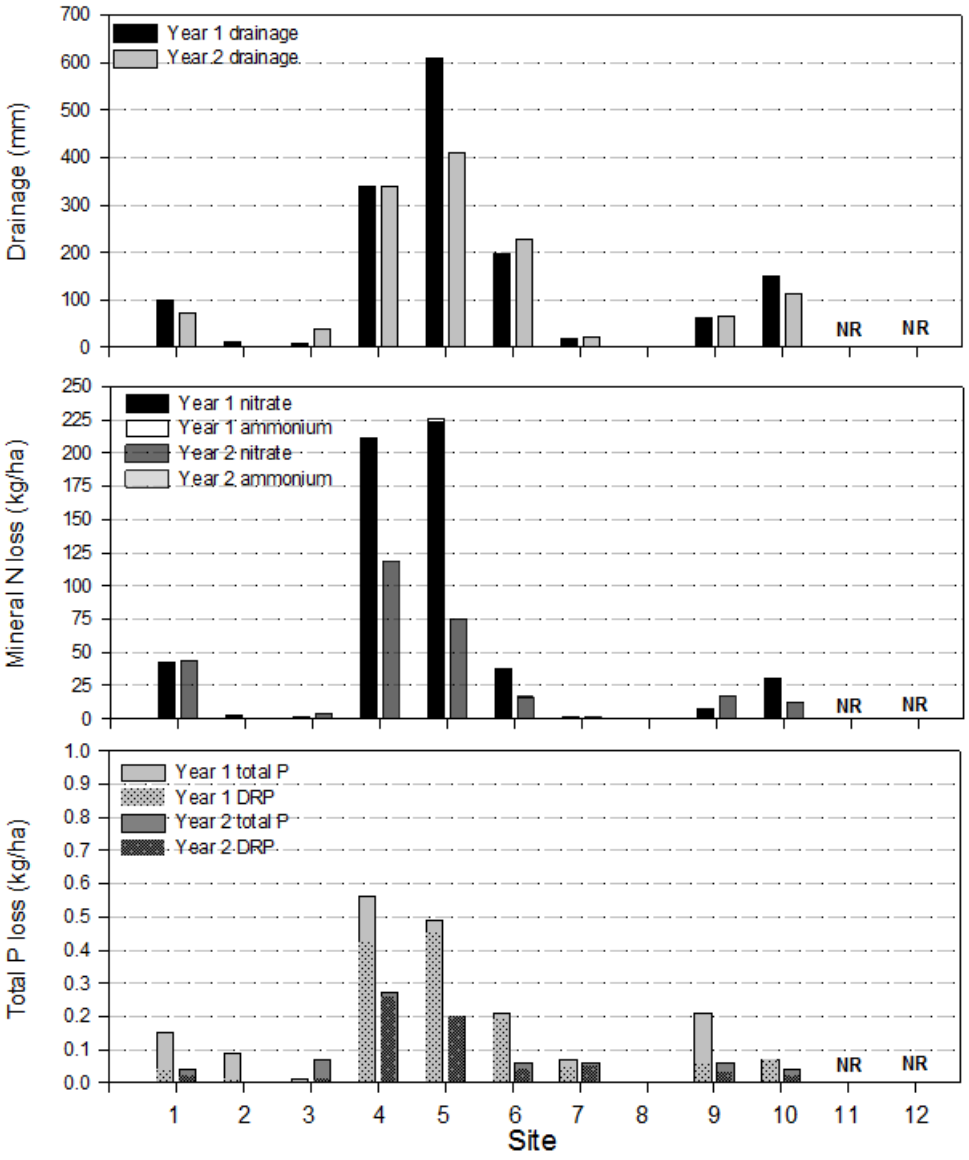

Figure i. Summary of drainage volumes and mineral N and total P losses in drainage across the 12 fluxmeter sites for the Year 1 (1 October 2014 to 30 September 2015) and Year 2 (1 October 2015 to 30 September 2016) monitoring periods. No results (NR) were obtained at Sites 11 and 12 due to flooding of the fluxmeter units.

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1 INTRODUCTION

Regional authorities around New Zealand are developing plans to improve freshwater quality while enabling sustainable intensification of agriculture. A common theme is the requirement that farmers should, as a minimum, be applying agricultural good management practice (GMP; Lambie, 2015). However, there is relatively little information available regarding the measured inter-annual nitrogen (N) and phosphorus (P) losses from the root zone of commercial cropping paddocks under GMP.

In July 2014 two new projects funded by the Ministry for Primary Industries (Sustainable Farming Fund), the Foundation for Arable Research, Horticulture NZ, Environment Canterbury, Horizons Regional Council, Hawke's Bay Regional Council, Waikato Regional Council, Auckland Regional Council and Ravensdown commenced to create a network of tension fluxmeters in commercial cropping farms in Canterbury, Manawatu, Hawke's Bay, Matamata and Pukekohe, and use these to measure losses of N and P in leachate water.

Results from this work will provide farmers and regional authorities with measurements of leaching losses from cropping farms across sites and seasons, and will be the basis for ongoing extension efforts to ensure GMPs are widely accepted and adopted by farmers. Data will also be available for future efforts to improve predictive models that can either be used to manage crops or inform policy development.

This report summarises activity from the network between 1 October 2014 and 30 September 2016. Not all sites have been operating for this entire period.

2 METHODS

2.1 Overview

In this project we have created a network of tension fluxmeters installed on contrasting commercial cropping farms in Canterbury, Manawatu, Hawke's Bay, Matamata and Pukekohe. Results from this work will provide farmers and regional authorities with robust measurements of nutrient leaching losses from cropping farms across sites and seasons under good management practices.

2.2 Tension fluxmeters

Leachate losses can be measured in a number of ways and each method has associated strengths and potential weaknesses. In this project nutrient concentrations in drainage water are being quantified using passive-wick tension fluxmeters. Tension fluxmeters have been used across a wide variety of land uses (e.g. pipfruit, kiwifruit, grapes, potatoes, leafy greens) in New Zealand for the past decade.

The design of fluxmeters is simple. The unit itself is made of cylindrical PVC piping which has a convergence zone where drainage water is intercepted as it moves down the soil profile. The units are 120 cm long and the convergence zone 20 cm wide (Figure 1). In the convergence zone fine sand is packed on top of diatomaceous earth to filter drainage water before it enters the storage tank (to reduce sediment transfer). A passive wick ensures that water only enters the storage tank when soil moisture is at or above field capacity, preventing preferential flow in to the tank. The maximum storage volume in each tank is 14 L. Attached to each fluxmeter are two small gauge plastic tubes to remove drainage water under suction during sampling events. Once installed, the units are designed to remain in the soil for an extended period.

The strengths of the fluxmeter units are that they provide a measure of losses under commercial practice, and that they are installed below the root zone so can be left in place for an extended period and capture a complete record of drainage events. The potential weaknesses that need to be managed include spatial variability (related to the narrow convergence zone), installation processes which disturb the soil profile and specific technical limitations (e.g. high water tables flood the units, installation is difficult in stony soils, artificial drainage above the units can result in erroneous results). Many of these issues are common across different methods for measuring leaching losses.

A summary of the design and functionality of fluxmeter units is provided by Gee et al. (2009) and Meissner et al. (2010).

Figure 1. Basic passive wick tension fluxmeter design installed at all sites. The units are installed below the soil surface, and intercept drainage water and hold it in a storage tank until sampling. Diatomaceous earth and fine sand are packed into the convergence zone to filter drainage water. The maximum storage volume is about 14 L.

2.3 Experimental design

The basic experimental design across the fluxmeter network includes four monitor regions, three sites per region and 12 fluxmeters per site. The top of the fluxmeters were installed to a depth of 1 m, selected to represent a depth below which nutrient uptake across most crop species is minimal.

The four monitor regions are Canterbury, Manawatu, Hawke's Bay and Matamata/Pukekohe[1], representing a number of significant cropping areas in New Zealand. All sites are located on commercial properties that were identified by the project partners as providing a range of cropping systems, soil types, climatic conditions and management practices relevant to each region.

In all cases site inspections were conducted before installation to review the project aims and approach with collaborating growers, identify suitable rotations and candidate sites on their farms, and assess any technical limitations at these sites (e.g. high water table, stony soils, artificial drainage). Collaborating growers were already applying a range of GMP's at the start of the project.

The layout of fluxmeters at a given site was in clusters of four units (Figure 2). Tubing from the individual fluxmeters within a cluster was trenched back to a central measurement hub. Within a cluster the approximate distance between fluxmeters was about 4 m; between clusters the approximate distance was 25 to 40 m.

The same experimental approach was used at all sites.

[1]The Canterbury, Manawatu and Hawke's Bay sites are part of the SFF Root Zone Reality Project (SFF 401484) and the Matamata/Pukekohe sites are part of an extension project (HortNZ RI 1009). Because the same approach has been adopted at all sites and the strength of the network is in the range of conditions it covers all sites have been reported together.

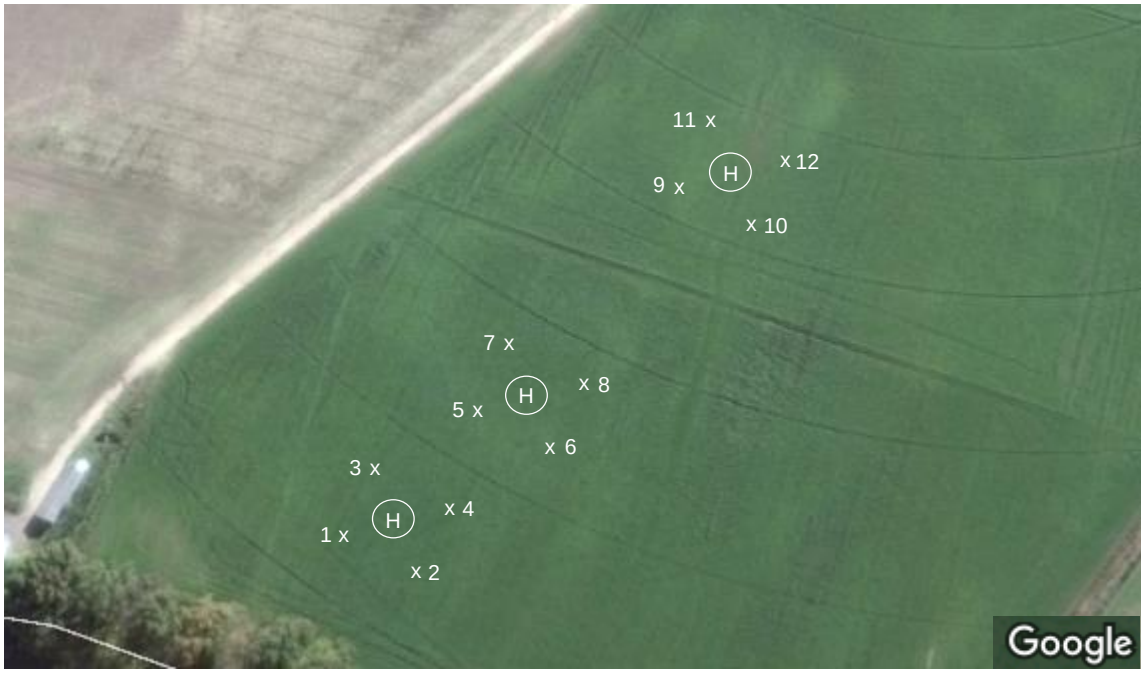

Figure 2. Example layout of fluxmeter units within a field. Clusters of four units were installed within a 4 m radius and tubing was trenched back to a central sampling hub (H). The distance between clusters depended on site features and ranged from 25 to 40 m.

2.4 Installation process

Installation of fluxmeters at each site typically occurred during the changeover of crops to minimise disruption to the farmer. Soil moisture conditions were carefully considered before installation to minimise potential repacking effects associated with excessively wet or dry soil.

The fluxmeter clusters were installed in representative and comparatively uniform areas of the site to minimise potential variability in results (the intent was to record an average site value under GMP, not extremes). This was assessed by topography, test holes and, where available, site-specific soil maps (e.g. S-map, EM profiles). Grower knowledge of their site was also used to cross-check the locations.

Fluxmeters were installed according to an established procedure. This included augering holes (diameter 200 mm) to a depth of 2.2 m. As the soil was removed it was placed in to ordered buckets in approximately 10 cm sampling intervals for subsequent repacking (Figure 3a). The top of the fluxmeter unit was designed to sit at 1 m below the surface, so soil from below 1 m was discarded.

Fluxmeters were carefully lowered into the holes and the profiles repacked with the stratified soil layers (Figure 3b). Repacking included compacting the soil firmly to mimic conditions prior to disturbance. Based on previous experience, 'settling effects' can last anywhere from 3 to 12 months, depending on the soil type and soil moisture conditions during repacking. Checks for resettling are conducted by comparing estimates of predicted drainage (using a validated soil water balance model) against actual drainage measurements. At most sites cultivation occurred soon after the fluxmeters were installed, meaning that disturbance of the soil profile (at least in the topsoil) was inevitable.

Tubing from individual fluxmeters was trenched back to a central hub (four fluxmeters per hub) at approximately 60 cm depth (below the depth of the deepest cultivation implement). The collection hubs were designed to minimise potential compaction effects over the fluxmeter units themselves (Figure 3c).

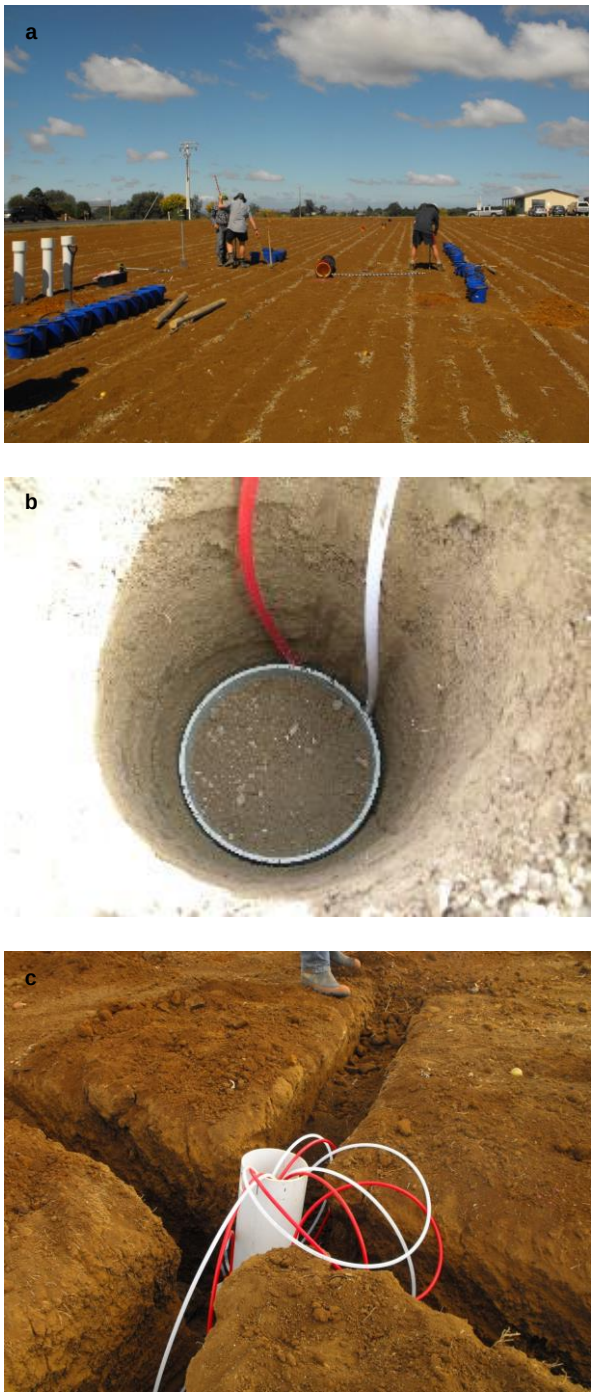

Figure 3. Example of the installation process showing (a) preparation of the holes for installation and soil being hand-augered into buckets according to depth, (b) lowering of the fluxmeters into holes, and (c) tubing coming from the individual fluxmeters back to central hub sampling points.

2.5 Measurements

A range of soil, plant and leachate measurements are being collected from the network sites.

2.5.1 Soil sampling

Soil samples are being collected at the start of each new crop sequence to quantify indicators of soil fertility. On each sampling occasion four samples are composited for each fluxmeter cluster across a range of sampling depths (0–20, 20–40, 40–60, 60–80 and 80–100 cm).

Samples from the 0–20 cm depth are being analysed for basic soil fertility indicators (pH, Olsen phosphorus [Olsen P], exchangeable cations and cation exchange capacity [CEC]) and soil nitrogen (N) characteristics (ammonium N, nitrate N, anaerobically mineralisable N (AMN), total N and total carbon [C]), whereas the deeper samples are only being analysed for N characteristics and total C.

For the purposes of this summary only mineral N (0–100 cm), AMN (0–100 cm) and Olsen P (0–20 cm) concentrations are reported and as site averages. Range values considered as 'low', 'moderate' or 'high' are listed in Table 1.

Table 1. Range values for mineral N, AMN and Olsen P considered as 'low', 'moderate' or 'high'.

Analyte	Low range	Moderate range	High range
Mineral N (kg N/ha, 0–100 cm)	0–50	50–150	> 150
AMN (kg N/ha, 0–100 cm)	0–100	100–200	> 200
Olsen P (mg/L, 0–20 cm)	0–20	20–50	> 50

2.5.2 Crop sampling

Crop samples are collected on two or three occasions during each crop sequence to quantify biomass productivity and N uptake. The number of sampling occasions reflects the duration of crop growth (typically two harvests for crops in the ground for < 5 months, and three harvests for crops in the ground for > 5 months).

On each occasion four samples are collected from each fluxmeter cluster. The size of the sample is specific to each crop (see Appendix 1 for a list of harvest protocols). In most cases, the final harvest is timed to coincide with the commercial harvest of each crop. Final harvest samples are also separated into two components: the plant material that is removed from the site during harvesting, and the plant material that is returned to the soil as residue. This information is important for considering nutrient cycling dynamics. In most cases, only the above-ground biomass is sampled; the exception is where below-ground biomass forms part of the marketable biomass (e.g. potato tubers, carrot roots).

In all cases, total fresh biomass is recorded and samples oven-dried to determine dry matter percentage (DM%); this is subsequently used to estimate total dry biomass of either the whole plant or marketable plant.

Samples are subsequently ground and analysed for total N concentration (one composite sample per fluxmeter cluster) and N uptake calculated.

2.5.3 Leachate sampling

Leachate samples are routinely collected from the fluxmeter units. The timing of sampling varies by site and season, reflecting irrigation practices, rainfall and key soil physical properties that influence drainage. A simple water balance model is used to assist in drainage predictions.

On each sampling occasion leachate is collected from individual fluxmeter units. The maximum number of samples on any sampling occasion is 12 (i.e. one per fluxmeter, assuming all units have captured drainage). Sampling involves using a suction pump to remove drainage water from the buried fluxmeters. The volume of drainage is then recorded and three 40 mL plastic tubes retained from each fluxmeter for further analyses (one for inorganic N and dissolved reactive phosphorus (DRP), one for Total P and one spare). Samples for inorganic N and DRP analysis are pre-filtered in the field using Axiva™ syringe filters (0.45 micron). The remaining samples are not filtered. Following collection the samples are frozen until further analysis.

2.6 Analyses

All analyses are performed by an IANZ-accredited laboratory following standard analytical procedures. In brief, soil indicators are measured according to the following procedures; pH, by electrode following extraction in distilled water (1:2.5 ratio); Olsen P by colourimetry following 0.5 M bicarbonate extraction, exchangeable cations by atomic emission spectroscopy (MP-AES) following 1.0 M ammonium acetate extraction (1:20 v/v ratio), nitrate-N by Cd reduction and NED colourimetry and ammonium-N by Berthelot colourimetry, both following extraction in 1.7 M KCl, AMN determined colourimetrically following a 7-day anaerobic assay, and total N and total C by Dumas combustion. CEC is calculated as the sum of exchangeable cations and the extractable acidity and mineral N as the sum of nitrate and ammonium N. Plant tissue N is measured by Dumas combustion. Leachate samples are measured according to the following procedures: nitrate-N by Cd reduction and NED colourimetry, ammonium N by Berthelot colourimetry, Total P by molybdate reduction following persulphate oxidation and DRP by molybdate reduction following 0.45 µm filtration.

2.7 Supplementary data

Weather data for each site (daily and long-term) is collated from the National Institute of Water and Atmospheric Research's (NIWA) climate database using observations from the nearest climate station. For some sites, a combination of stations is used to provide the required data. Observations included daily air temperature (minimum, mean and maximum), solar radiation, rainfall, vapour pressure, wind run and mean sea level (MSL) pressure (Appendix 2).

2.8 Data management

Statistical corrections have been applied to site estimates of drainage volume and nutrient concentrations to balance for the spatial arrangement of the fluxmeters in clusters and associated issues with non-overlapping data. Checks have also been performed on measured drainage volumes using a water balance model that accounts for daily rainfall, irrigation, crop water use and soil hydraulic properties. Where measured drainage volumes are greatly different from those estimated by the water balance, the leachate volumes and associated laboratory analyses have been omitted from this report. The number of samples comprising site averages for a given sampling occasion is noted in the individual sections below.

3 RESULTS

Results have been collated by each individual site and reflect the period 1 October 2014 to 30 September 2015 (Year 1) and the period 1 October 2015 to 30 September 2016 (Year 2). Fluxmeter installation dates varied across sites, reflecting the range of rotations and specific soil conditions at each site. All Canterbury sites were installed by September 2014, Manawatu sites by April 2015, Hawke's Bay sites by October 2014 and Matamata/Pukekohe sites by May 2015.

The key content summarised for each site can be broadly grouped according to the following categories: background site and crop management practices, weather summaries, soil fertility indicators, soil water balances and N and P leachate losses.

Data that were collected but not included in this report included detailed soil fertility and crop biomass measurements. These data are being collected for future model validations.

3.1 Site 1 — Canterbury

3.1.1 Background site and crop management history

Site 1 is located near Methven on a mixed cropping and livestock grazing enterprise. Soil type is a Mayfield silt loam. Fluxmeters were installed at the site in August 2014 into an established ryegrass seed crop sown in March 2013. Key site characteristics are described in Table 2.

Table 2. Summary of key farm and site characteristics, Site 1 — Canterbury.

Location	Methven
Farming system	Mixed cropping, winter livestock grazing
Topography	Flat
Soil type	Mayfield silt loam
Key soil characteristics[1]	Soil order: Typic argillic pallic Texture: Silt loam Topsoil bulk density: 1.22 g/cm^3 Subsoil bulk density: 1.53 g/cm^3 Drainage class: Moderate N leaching vulnerability: Medium
Previous land use history	Converted from dryland cropping in 2004 to irrigated cropping and livestock grazing.
Fluxmeter installation date	26 August 2014
Irrigation infrastructure	Centre pivot

[1]A full description of the Mayfield silt loam is available online at https://smap.landcareresearch.co.nz/home. Listed characteristics are taken from S-MAP factsheets and are not based on measured site values.

Since installation of the fluxmeters there have been four crops including ryegrass seed, ryegrass pasture, spring wheat and barley (Table 3). The established ryegrass crop (harvested for seed in January 2015 and subsequently grazed in July 2015) was sprayed off in August 2015 in preparation for spring wheat. Following conventional cultivation, spring wheat was sown on 21 August 2015. The wheat crop was harvested in March 2016 and the site sown with barley (the current crop) in April 2016. Respective N and P inputs have totalled 266 kg N/ha and 0 kg P/ha (ryegrass seed), 216 kg N/ha and 0 kg P/ha (ryegrass pasture), 306 kg N/ha and 15 kg P/ha (spring wheat) and 256 kg N/ha and 21 kg P/ha (barley) (Table 3).

Table 3. Summary of crop management practices since fluxmeter installation (26 August 2014), Site 1 — Canterbury.

Crop management practices	Sequence 1 — Ryegrass seed	Sequence 2 — Ryegrass pasture	Sequence 3 — Spring wheat	Sequence 4 — Barley
Variety	'Barrier'	'Barrier'	'Discovery'	'Pudura'
Planting population	12 kg seed/ha	Same crop	112 kg/ha	92 kg/ha
Planting date	March 2013	March 2013	21 August 2015	16 April 2016
Harvest date[1]	26 January 2015	12 August 2015[2]	10 March 2016	Current crop
Cultivation practices	Minimum tillage	None	Ploughed	Grubber followed by maxi-till
Fertiliser practices (product)[3]	150 kg/ha Ammo36 (S) 405 kg/ha Urea (S)[4] 125 kg/ha Ammonium Sulphate (S)	50 kg/ha KCl (S) 470 kg/ha Urea (S)[5]	65 kg/ha Urea (B) 273 kg/ha 30% Potash Sulphur Super (S) 601 kg/ha Urea (S)[6]	300 kg/ha Sulphur Super (B) 60 kg/ha Potassium Chloride (S) 129 kg/ha Ammo 31 (S) 470 kg/ha Urea (S)[7]
Summed N and P (elemental)	N = 266 kg/ha P = 0 kg/ha	N = 216 kg/ha P = 0 kg/ha	N = 306 kg/ha P = 15 kg/ha	N = 256 kg/ha P = 21 kg/ha
Stock type	Lambs	Dairy cows (in calf)	-	-
Stock density	25 lambs/ha	17 cows/ha	-	-
Additional stock information	Grazed from early September to early October 2014	Grazed in July 2015	-	-

[1]Commercial harvest date. [2]Reflects the date the ryegrass was sprayed off.[3]B = base application, P = planting application, S= side dressing application(s); note – details on base and planting applications were not available for sequence 1. [4]Split over three applications between October and November 2014. [5]Split over four applications between January and May 2015. [6]Split over six applications between August and December 2015. [7]Split over three applications between September and November 2016.

3.1.2 General weather conditions

Year 1 (1 October 2014 to 30 September 2015)

Rainfall for the Year 1 period totalled 416 mm (Figure 4a), 44% below the long-term average for the region (748 mm). The mid-summer to autumn period (January to May 2015) was very dry with only 79 mm rainfall recorded, 75% less than the long-term average for this period (322 mm).

Mean air temperature for the 12 month period was 10.3°C, cooler than the long-term average (11.2°C) (Figure 4b) while solar radiation totalled 4930 MJ/m^2, comparable to the long-term average of 4764 MJ/m^2 (Figure 4c).

Year 2 (1 October 2015 to 30 September 2016)

Rainfall for the Year 2 period totalled 536 mm, 28% less than the long-term average for the region (Figure 4a). The winter to early spring period (June to September) was particularly dry with 138 mm rainfall recorded, 41% less than the long-term average for this period (234 mm).

Mean air temperature over the 12 month period averaged 11.1°C while solar radiation totalled 475 MJ/m^2, both comparable to the long-term averages for the area (Figures 4b and c).

3.1.3 Soil nitrogen and phosphorus fertility levels

Soil samples for N and P fertility analyses were taken during installation of the fluxmeters in September 2014, 2 weeks after sowing of the spring wheat crop in September 2015 and 5 days after sowing of the barley crop in April 2016.

Mineral N (0–100 cm)

Samples taken in September 2014 had moderate concentrations of mineral N (98 kg N/ha), while concentrations for samples taken in September 2015 and April 2016 were high (287 and 239 kg N/ha respectively) (Figure 5a). For all sampling occasions the predominant form of mineral N was nitrate-N (51–90%), although ammonium-N concentrations were elevated in the September 2014 samples. For samples taken in September 2015, high mineral N concentrations were consistent with urine deposition during the 2015 winter grazing period in conjunction with previous N fertiliser applications (Table 3).

AMN (0–100 cm)

AMN concentrations were high for the September 2014 and September 2015 samples (257 – 266 kg N/ha) and reflected high levels of potentially mineralisable N (Figure 5a). High AMN concentrations were consistent for samples taken under long-term pasture or shortly after conversion to cropping. In contrast, AMN concentrations were considerably lower for the April 2016 samples (89 kg N/ha) and likely reflected the mineralisation of organic N forms during the previous crops.

Olsen P (0–20 cm)

Olsen P concentrations (0–20 cm depth) were low for all sampling occasions (12 to 14 mg/L respectively) and below normal concentrations suggested for ryegrass seed, spring wheat and barley production (20–30 mg/L) (Figure 5b).

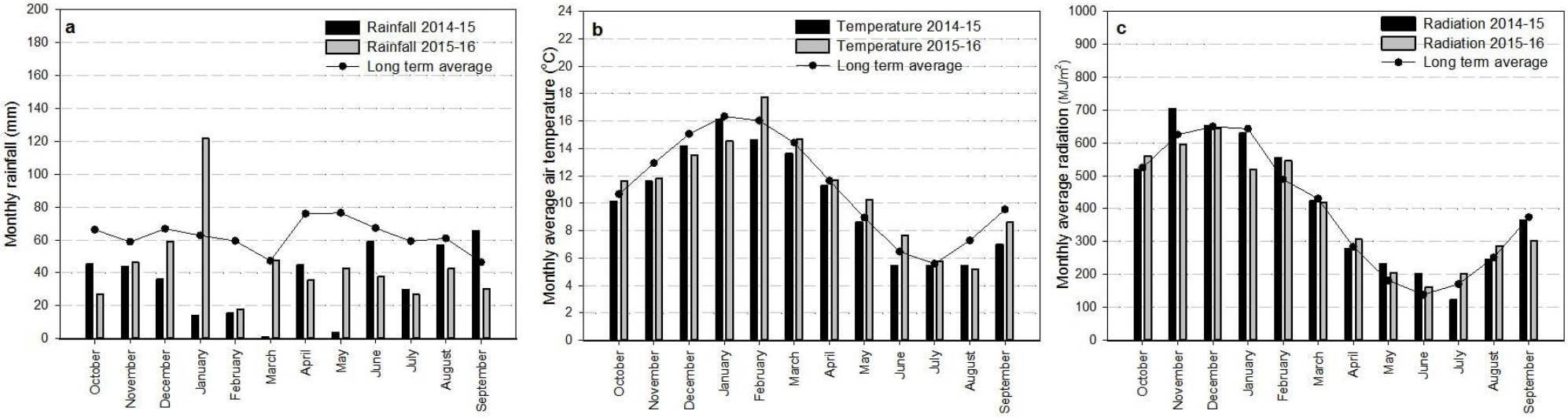

Figure 4. Monthly (a) rainfall (mm), (b) average air temperature (°C) and average solar radiation (MJ/m^2) for 1 October 2014 to 30 September 2016 at Methven (NIWA Station 37920). Long-term climate data (2001–14) are presented for the Winchmore station (NIWA Station 4764).

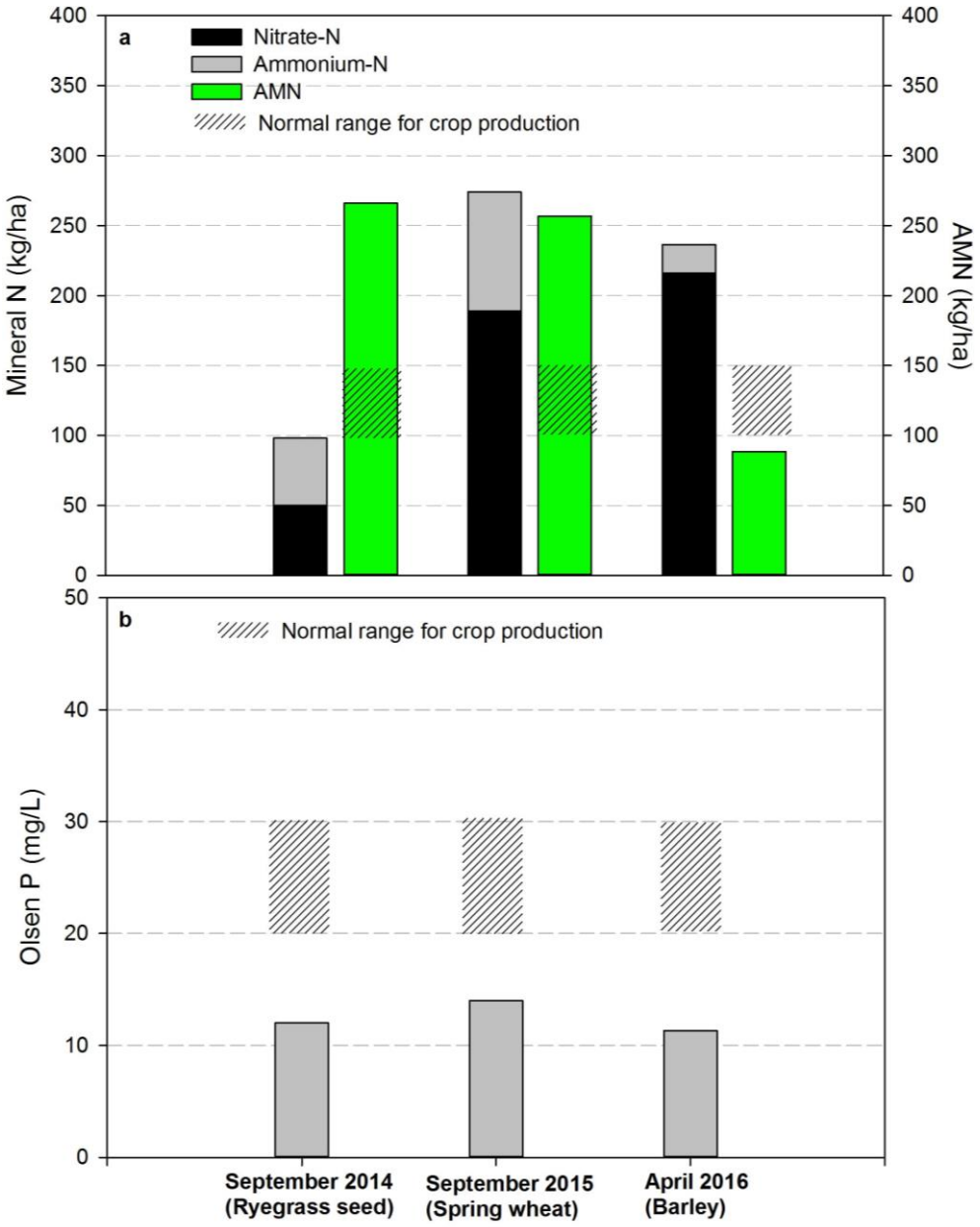

Figure 5. Soil mineral N and AMN (0–100 cm depth) (a) and Olsen P (0–20 cm depth) (b) at Site 1 — Canterbury for samples taken in September 2014, September 2015 and April 2016. Normal ranges suggested for crop production are provided by Hill Laboratories (http://www.hill-laboratories.com/page/pageid/2145845703/Crop_Guides)

3.1.4 Soil water balance

Year 1 (1 October 2014 to 30 September 2015)

The soil water balance for Site 1 is shown in Figure 6. Rainfall and irrigation for the Year 1 period totalled 416 mm and 268 mm respectively. There was only one rainfall event over 50 mm which occurred in mid-June 2015 (56 mm over 2 days). The range in individual irrigation application volumes was 4–35 mm.

For all depths, there was a decreasing trend in modelled soil water contents between October 2014 and June 2015, consistent with a very dry mid-summer to autumn period. Modelled soil water contents then increased over the mid-winter to sprig period in response to more frequent rainfall events. Most drainage was collected over this period (July to September 2015).

Year 2 (1 October 2015 to 30 September 2016)

Rainfall and irrigation for the Year 2 period totalled 536 mm and 207 mm respectively. The largest rainfall event was in late January (44 mm recorded over 2 days) while the range in individual irrigation application volumes was 5–20 mm (Figure 6).

In contrast to the Year 1 monitoring period, there was an increasing trend in modelled soil water contents over the monitoring period, likely reflecting a degree soil moisture recharge following the previous dry year. For the 0–30 cm depth, modelled soil water contents increased to high levels (>80 mm) over the summer period (December to February), reflecting frequent irrigation events. In general, levels remained above 60 mm for the duration of the monitoring period. Modelled soil water contents for the 30–60 and 60–90 cm depths decreased slightly over the mid-spring to summer period (October to February) before increasing to comparably high levels (> 60 mm) for the duration of the late autumn to early spring period (May to September). Drainage was collected on a consistent basis between mid-November 2015 and late August 2016.

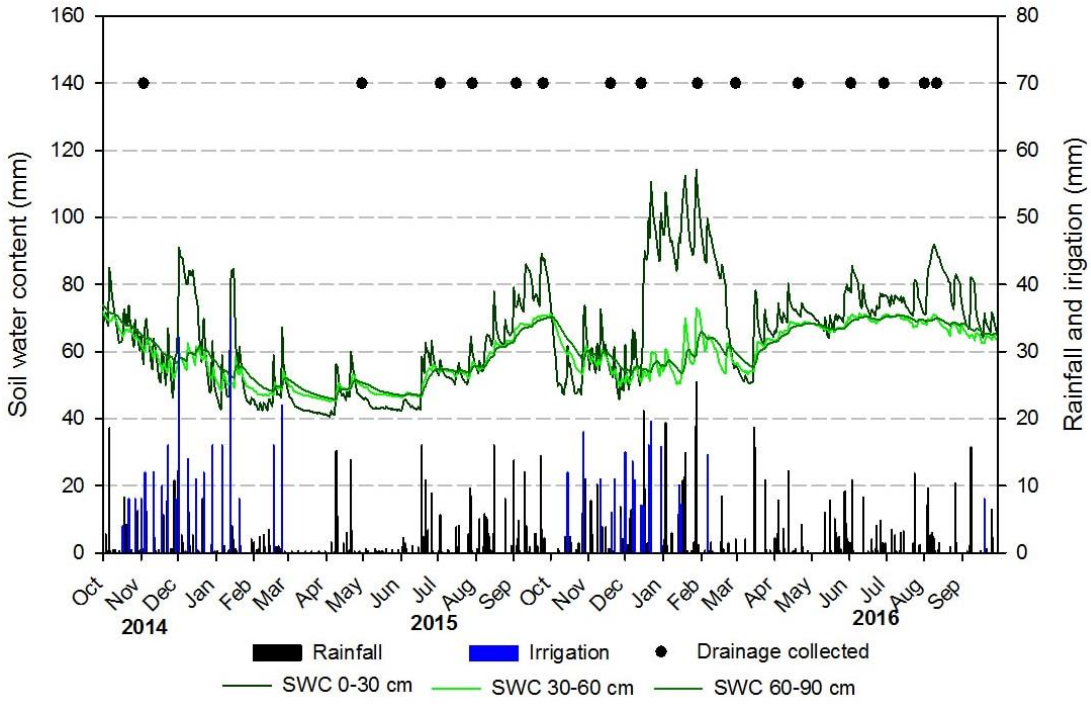

Figure 6. Summary of daily rainfall, irrigation and modelled soil water content (0–30 cm, 30–60 cm and 60–90 cm) for the period 1 October 2014 to 30 September 2016, Site 1 — Canterbury. Fluxmeter units were installed on 26 August 2014.

3.1.5 Losses of N and P in drainage water

Year 1 (1 October 2014 to 30 September 2015)

Drainage samples were collected on six occasions in the first year following installation of the fluxmeters (Figure 7b). Total drainage volume was 101 mm.

Nitrate-N and ammonium-N concentrations in drainage for this period averaged 26.2 mg/L and 3.1 mg/L respectively (Figure 7b). Nitrate-N concentrations tended to increase over this period and peaked at 36.6 mg/L in late July 2015, while ammonium-N concentrations remained low for the duration of this period. Measured mineral N losses from the system totalled 43 kg N/ha (Figure 7c) with the majority of N lost as nitrate-N (42 kg N/ha). Losses were elevated for the period July to September (39 kg N/ha), consistent with increased drainage volumes and elevated nitrate-N concentrations.

Total P and DRP concentrations averaged 0.39 mg/L and 0.25 mg/L respectively (Figure 8b). Overall, net P losses were low, totalling 0.15 kg P/ha with DRP loss accounting for 0.04 kg P/ha. The observed decline in the concentration difference between total P and DRP over the monitoring period suggests a net decrease in the transfer of dissolved organic P and/or sediment bounds P forms (> 0.45 µm). This most likely reflects a soil 'settling effect' following installation of the fluxmeter units.

Year 2 to date (1 October 2015 to 30 September 2016)

Drainage samples were collected on nine occasions in the second year following installation of the fluxmeters (Figure 7b). Total drainage volume was 74 mm.

Nitrate-N and ammonium-N concentrations in drainage for this period averaged 43.4 mg/L and 0.4 mg/L respectively (Figure 7b). Nitrate-N concentrations trended upwards over this period peaking at 63.0 mg/L in mid-August 2016. Measured mineral N losses from the system totalled 44 kg N/ha (Figure 7c) with N lost almost entirely as nitrate-N. Losses were comparable to those observed in Year 1 (42 kg N/ha).

Total P and DRP concentrations averaged 0.07 mg/L and 0.06 mg/L respectively (Figure 8b). Measured P losses from the system over this period were minimal (< 0.05 kg P/ha; Figure 8c).

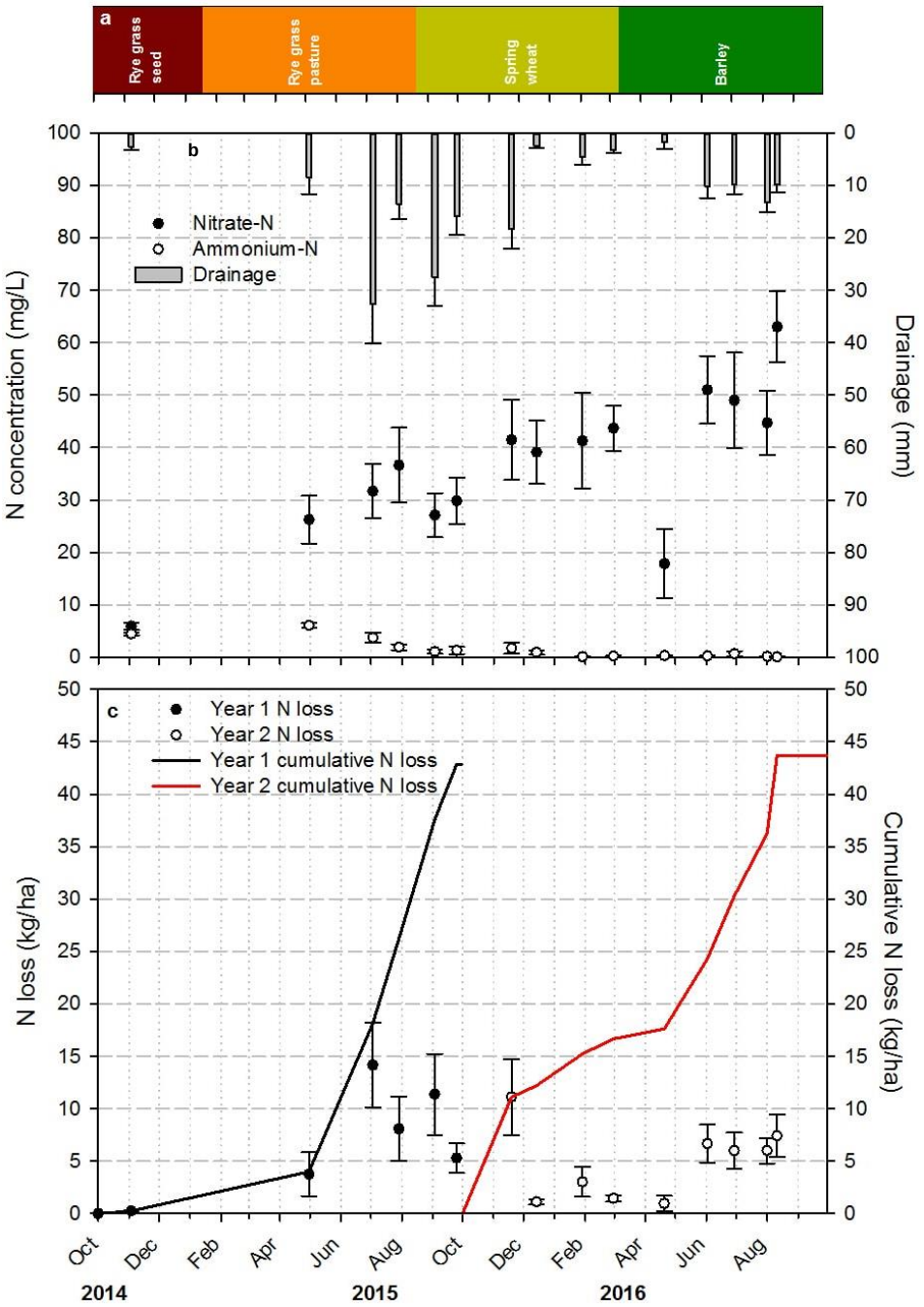

Figure 7. Summary of crop sequence (a), measured drainage and inorganic N concentrations (nitrate-N and ammonium-N) in drainage (b) and measured system losses of inorganic N in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) (c) Site 1 — Canterbury. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: nitrate-N: 0.02 mg/L; ammonium-N: 0.01 mg/L. Fluxmeters were installed on 26 August 2014.

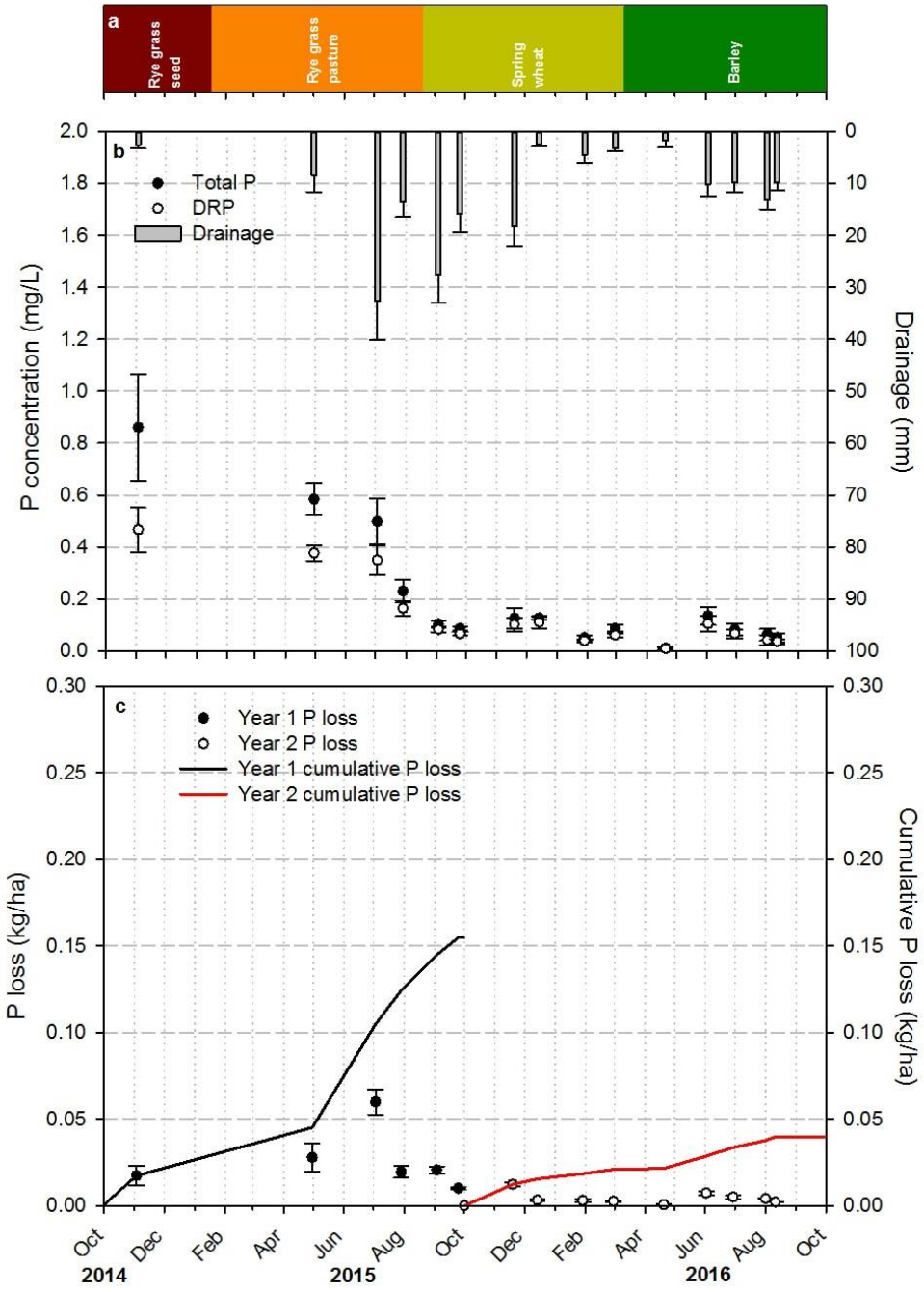

Figure 8. Summary of crop sequence (a), measured drainage and P concentrations (total P and DRP) in drainage (b) and measured system losses of total P in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) (c) Site 1 — Canterbury. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: Total P: 0.02 mg/L; DRP: 0.001 mg/L. Fluxmeters were installed on 26 August 2014.

3.2 Site 2 – Canterbury

3.2.1 Background site and crop management history

Site 2 is located near Methven on a mixed cropping and livestock grazing enterprise. Soil type is a Barrhill silt loam. Fluxmeters were installed at the site in September 2014 following a ryegrass crop. Key site characteristics are described in Table 4.

Table 4. Summary of key farm and site characteristics, Site 2 — Canterbury.

Location	Methven
Farming system	Mixed cropping, livestock grazing
Topography	Flat
Soil type	Barrhill silt loam
Key soil characteristics[1]	Soil order: Typic immature pallic Texture: Silt loam Topsoil bulk density: 1.22 g/cm^3 Subsoil bulk density: 1.42 g/cm^3 Drainage class: Well drained N leaching vulnerability: Medium
Previous land use history	Mixed cropping and livestock grazing for more than 10 years.
Fluxmeter installation date	22 September 2014
Irrigation infrastructure	Gun

[1]A full description of the Barhill silt loam is available online at https://smap.landcareresearch.co.nz/home. Listed characteristics are taken from S-MAP factsheets and are not based on measured site values.

Since installation of the fluxmeters there have been three crops including two crops of barley and one crop of white clover (Table 5). The first barley crop was sown in October 2014 and harvested in February 2015. The site was subsequently sown with white clover in March 2015 and harvested for seed in February 2016. The clover crop was retained over the autumn and winter period for grazing by lambs before being terminated in mid-August 2016. Carrots (the current crop) were planted in late September 2016. Respective N and P inputs have totalled 154 kg N/ha and 18 kg P/ha (barley) and 22 kg N/ha and 32 kg P/ha (carrots). No fertiliser was applied to the clover crop (Table 5).

Table 5. Summary of crop management practices since fluxmeter installation (22 September 2014), Site 2 — Canterbury.

Crop management practices	Sequence 1 — Barley	Sequence 2— White clover (seed)	Sequence 3 — White clover (grazing)	Sequence 4— Carrots
Variety	'Summit'	Information not available	Information not available	'Carson'
Planting population	120 kg/ha	3 kg/ha	3 kg/ha	40 kg/ha
Planting date	16 October 2014	20 March 2015	20 March 2015	30 September 2016
Harvest date[1]	1 March 2015	10 February 2016	15 August 2016[2]	Current crop
Cultivation practices	Ploughed, grubbed twice and drilled	Heavy rolled, direct drilled	-	Shallow grubbed x2, ploughed, grubbed, and rolled followed by power harrow.
Fertiliser practices (product)[3]	150 kg/ha Urea (B) 8 kg/ha 50:50 mix of CropMaster15/Carrot Brew (B) 150 kg/ha Urea (S)[4]	No fertiliser applied	4000 kg/ha lime (S) 1000 kg/ha dolomite (S)	125 kg/ha DAP (B) 225 kg/ha potassium sulphate (B) 100 kg/ha serpentine super (B) 20 kg/ha borate 46 (B) 12 kg/ha zinc sulphate (B) 8 kg/ha copper sulphate (B)
Summed N and P (elemental)	N = 154 kg/ha P = 18 kg/ha	N = 0 kg/ha P = 0 kg/ha	N = 0 kg/ha P = 0 kg/ha	N = 22 kg/ha P = 32 kg/ha
Stock type	No stock	Lambs	Lambs	-
Stock density	-	46 lambs/ha	Average 22 lambs/ha	-
Additional stock information	-	600 lambs grazed for 3 days in May to remove barley regrowth 600 lambs grazed for 7 days in November	200 lambs in mid-April for 51 days, additional 250 lambs added mid-May for 21 days 250 lambs grazed for 20 days from late July	-

[1]Commercial harvest date. [2]Reflects the date the clover crop was terminated. [3]B = base application, P = planting application, S= side dressing application(s). [4]Applied as a single application in late November 2014.

3.2.2 General weather conditions

Year 1 (1 October 2014 to 30 September 2015)

Rainfall for the Year 1 period totalled 565 mm, 24% below the long-term average for the region (748 mm) (Figure 9a). The late spring to summer period (October 2014 to February 2015) was particularly dry with only 135 mm recorded, 57% less than the long-term average of 314 mm.

Mean air temperature for the 12 month period was 10.7°C, cooler than the long-term average (11.2°C) (Figure 9b) while solar radiation totalled 5110 MJ/m^2, slightly higher than the long-term average of 4764 MJ/m^2 (Figure 9c).

Year 2 (1 October 2015 to 30 September 2016)

Rainfall and mean air temperature for the Year 2 period totalled 484 mm, 35% below the long-term average for the region (Figure 9a). The winter and early spring period (June to September 2016) was particularly dry with only 125 mm recorded, 47% less than the long-term average for this period (234 mm).

Mean air temperature for the 12 month period was 11.6°C, warmer than the long-term average (Figure 9b) while solar radiation totalled 5039 MJ/m^2, slightly higher than the long-term average (Figure 9c)

3.2.3 Soil nitrogen and phosphorus fertility levels

Soil samples for N and P fertility analyses were taken shortly after installation of the fluxmeters in September 2014, 3 weeks following sowing of white clover in April 2015 and 5 weeks before sowing of the barley crop in August 2016.

Mineral N (0–100 cm)

Mineral concentrations were low for samples taken in September 2014 (61 kg N/ha), moderate for samples taken in April 2015 (134 kg N/ha) and high for samples taken in August 2016 (229 kg N/ha) (Figure 10a). Samples taken in September 2014 and August 2016 had elevated concentrations of ammonium-N (49 to 74% of mineral N), whereas nitrate-N was the predominant form of mineral N (84%) for samples taken in April 2015. The high mineral N concentrations for the August 2016 samples were consistent with the previous crop type (N fixing legume) and management practice (grazed by lambs for the preceding months) (Table 5).

AMN (0–100 cm)

AMN concentrations increased from moderate in the September 2014 and April 2015 samples (156–183 kg N/ha) to high for the August 2016 samples (244 kg N/ha). For all sampling occasions, AMN concentrations were above normal concentrations suggested for barley and white clover production (100–150 kg N/ha).

Olsen P (0–20 cm)

Olsen P concentrations remained consistently low across all sampling occasions (15–16 mg/L) and below normal concentrations suggested for barley and white clover production (20–30 mg/L) (Figure 10b).

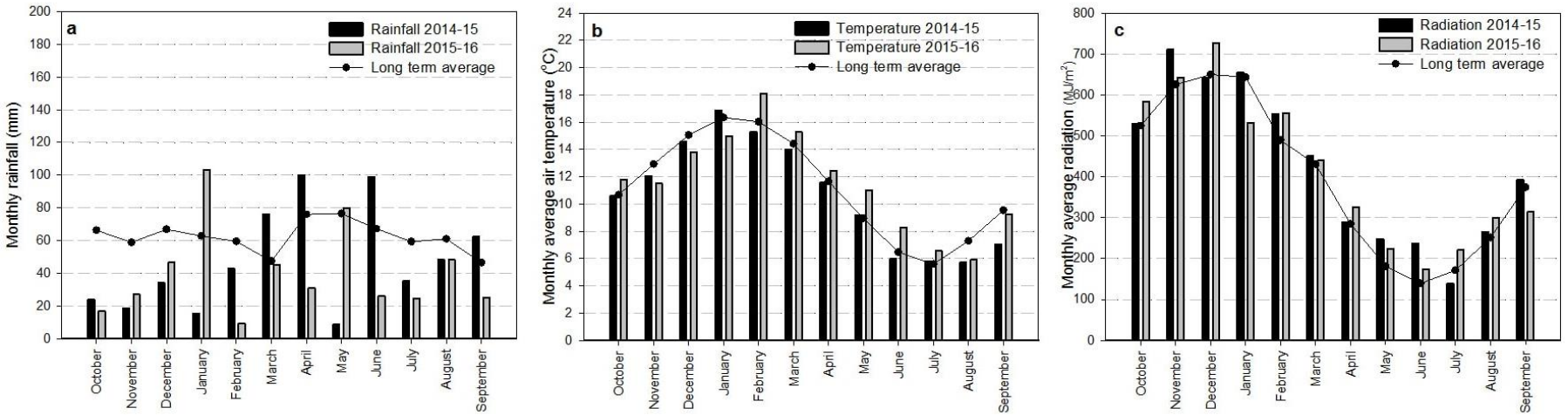

Figure 9. Monthly (a) rainfall (mm), (b) average air temperature (°C) and average solar radiation (MJ/m^2) for 1 October 2014 to 30 September 2016 at Methven (NIWA Station 37920). Long-term climate data (2001–14) are presented for the Winchmore station (NIWA Station 4764).

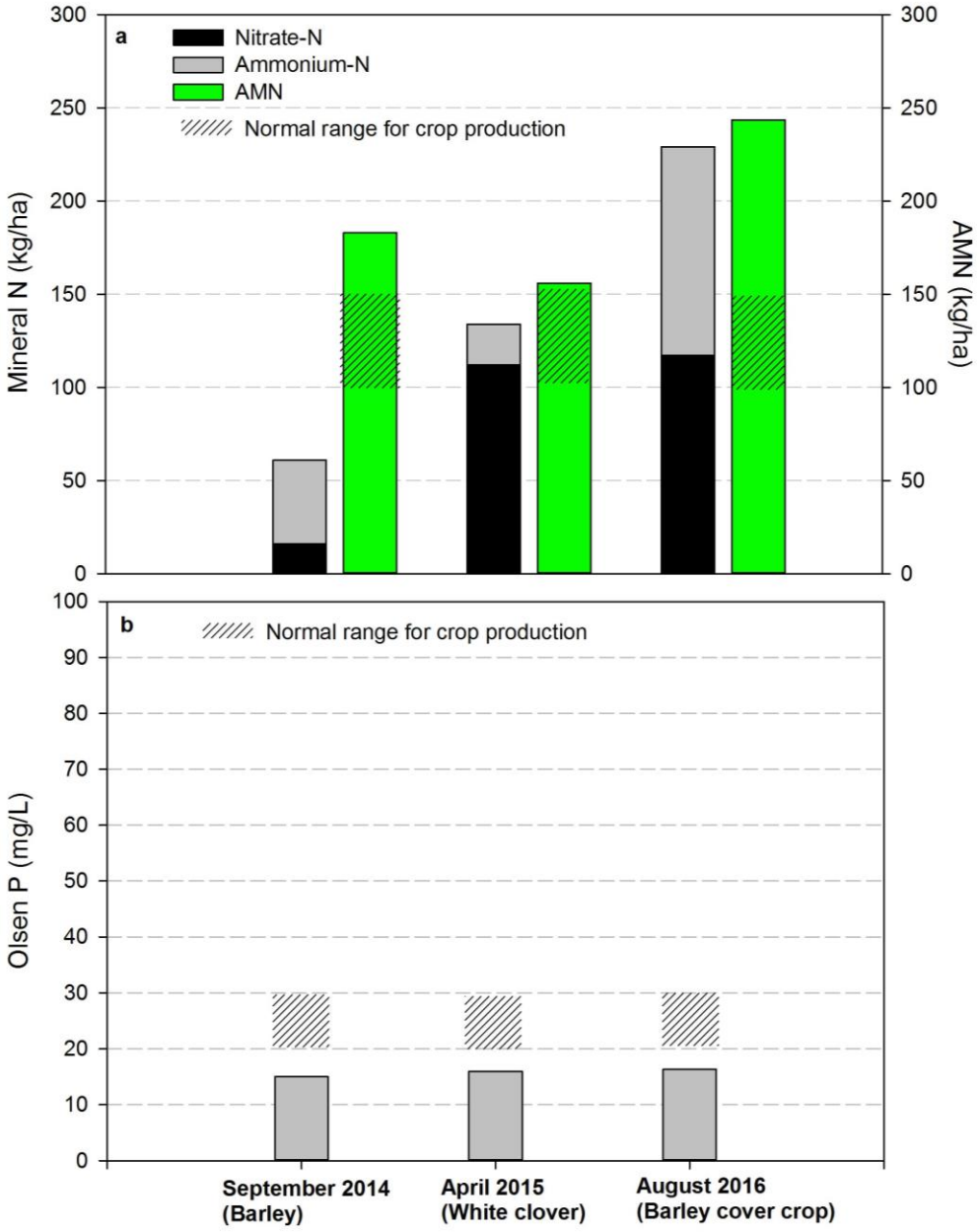

Figure 10. Soil mineral N and AMN (0–100 cm depth) (a) and Olsen P (0–20 cm depth) (b) at Site 2 — Canterbury for samples taken in September 2014, April 2015 and August 2016. Normal ranges suggested for crop production are provided by Hill Laboratories (http://www.hill-laboratories.com/page/pageid/2145845703/Crop_Guides).

3.2.4 Soil water balance

Year 1 (1 October 2014 to 30 September 2015)

The soil water balance for Site 2 is shown in Figure 11. Rainfall and irrigation for the Year 1 period totalled 647 mm and 145 mm respectively. There was one rainfall event over 50 mm that occurred in late June 2015 (75 mm over 1 day). The range in individual irrigation application volumes was 35–40 mm.

Modelled soil water contents for the 30–60 cm and 60–90 cm depths tended to increase from mid-January 2015 and remained elevated (> 100 mm) from mid-June 2015. Fluxmeter drainage samples were collected from late July 2015.

Year 2 (1 October 2015 to 30 September 2016)

Rainfall and irrigation for the Year 2 period totalled 484 mm and 60 mm respectively. The largest rainfall events occurred in late January and mid-March when 38 mm and 36 mm were recorded in a single day respectively (Figure 11). All irrigation was applied in a single application in mid-February.

Modelled soil water contents decreased at all depths from October onwards and remained at comparably low levels (< 50 mm) for the 30–60 and 60–90 cm depths for the duration of the summer period (December to February). They increased slightly over the winter and early spring period (June to September). The only drainage sample was collected in mid-November 2015.

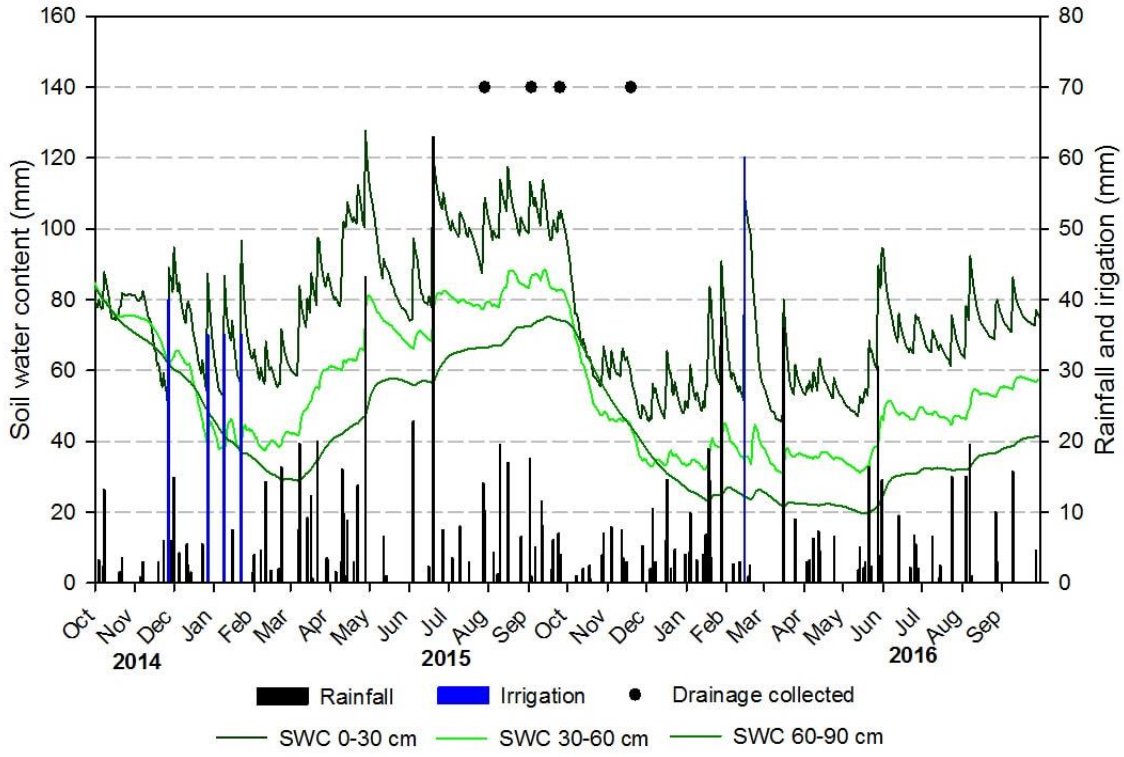

Figure 11. Summary of daily rainfall, irrigation and modelled soil water content (0–30 cm, 30–60 cm and 60–90 cm) from 1 October 2014, Site 2 — Canterbury. Fluxmeter units were installed on 22 September 2014.

3.2.5 Losses of N and P in drainage water

Year 1 (1 October 2014 to 30 September 2015)

Drainage samples were collected on three occasions in the first year following installation of the fluxmeters (Figure 12b). Total drainage volume was 13 mm.

Nitrate-N and ammonium-N concentrations in drainage for this period averaged 22.3 mg/L and 9.3 mg/L respectively (Figure 12b). Due to low drainage volumes, measured mineral N losses were low totalling 2.6 kg N/ha (Figure 12c) with the majority of mineral N lost as nitrate-N (2.0 kg N/ha).

Total P and DRP concentrations averaged 0.96 mg/L and 0.69 mg/L respectively (Figure 13b). Measured P losses from the system over this period were minimal (< 0.1 kg P/ha; Figure 13c).

Year 2 (1 October 2015 to 30 September 2016)

Drainage samples were collected on one occasion in the second year following installation of the fluxmeters (Figure 12b). Total drainage volume of 1 mm.

Respective nitrate-N and ammonium-N concentrations in this sample were 18.6 and 4.1 mg/L (Figure 12b). Due to low drainage volumes, there was sufficient sample for only DRP analyses. DRP in drainage for this event averaged 0.26 mg/L (Figure 13b). Due to low drainage volumes, measured mineral N and DRP losses were very low (< 0.5 kg N/ha and < 0.1 kg P/ha; Figures 12c and 13c respectively).

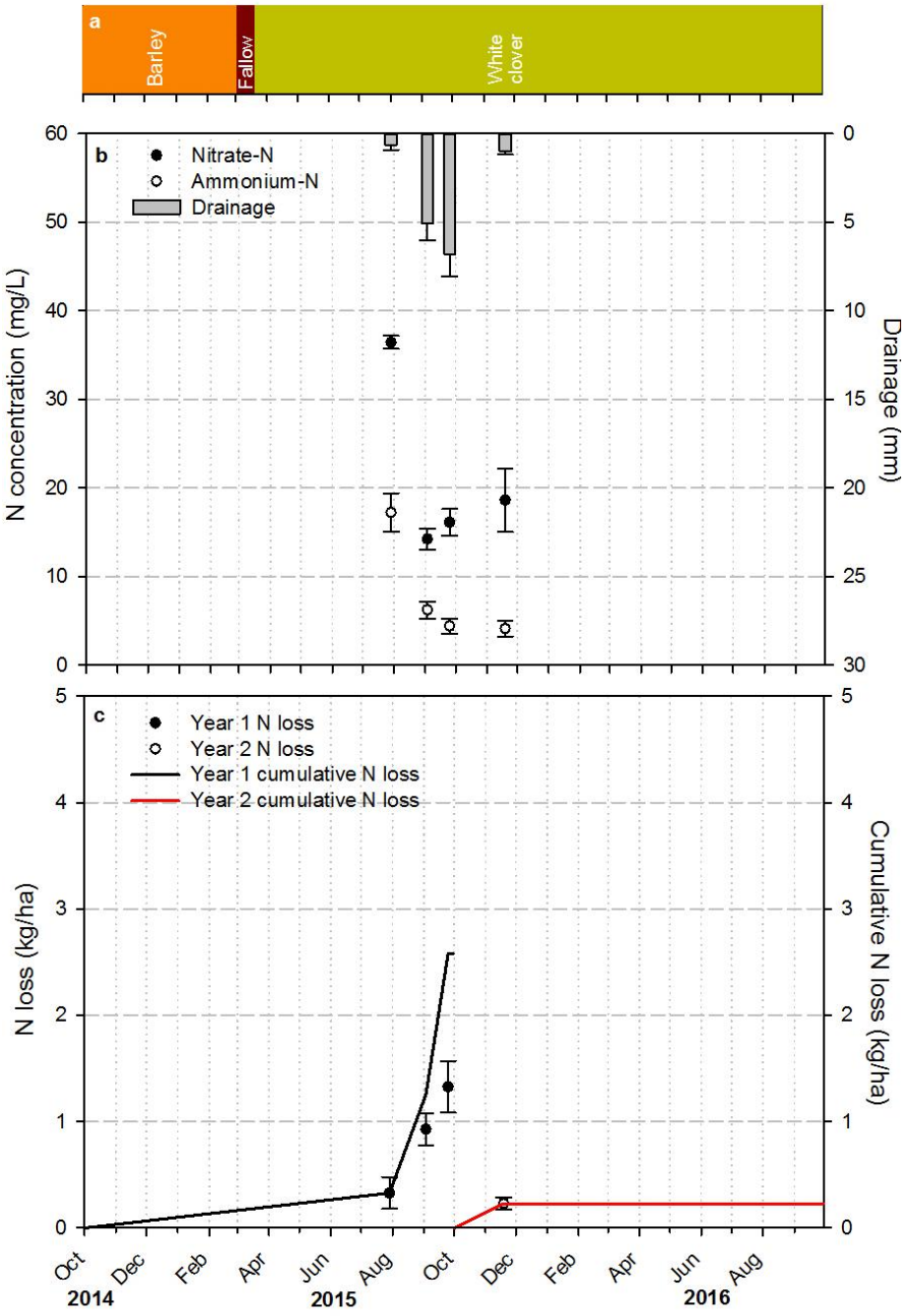

Figure 12. Summary of crop sequence (a), measured drainage and inorganic N concentrations (nitrate-N and ammonium-N) in drainage (b) and measured system losses of inorganic N in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) (c) Site 2 — Canterbury. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: nitrate-N: 0.02 mg/L; ammonium-N: 0.01 mg/L. Fluxmeters were installed on 22 September 2014.

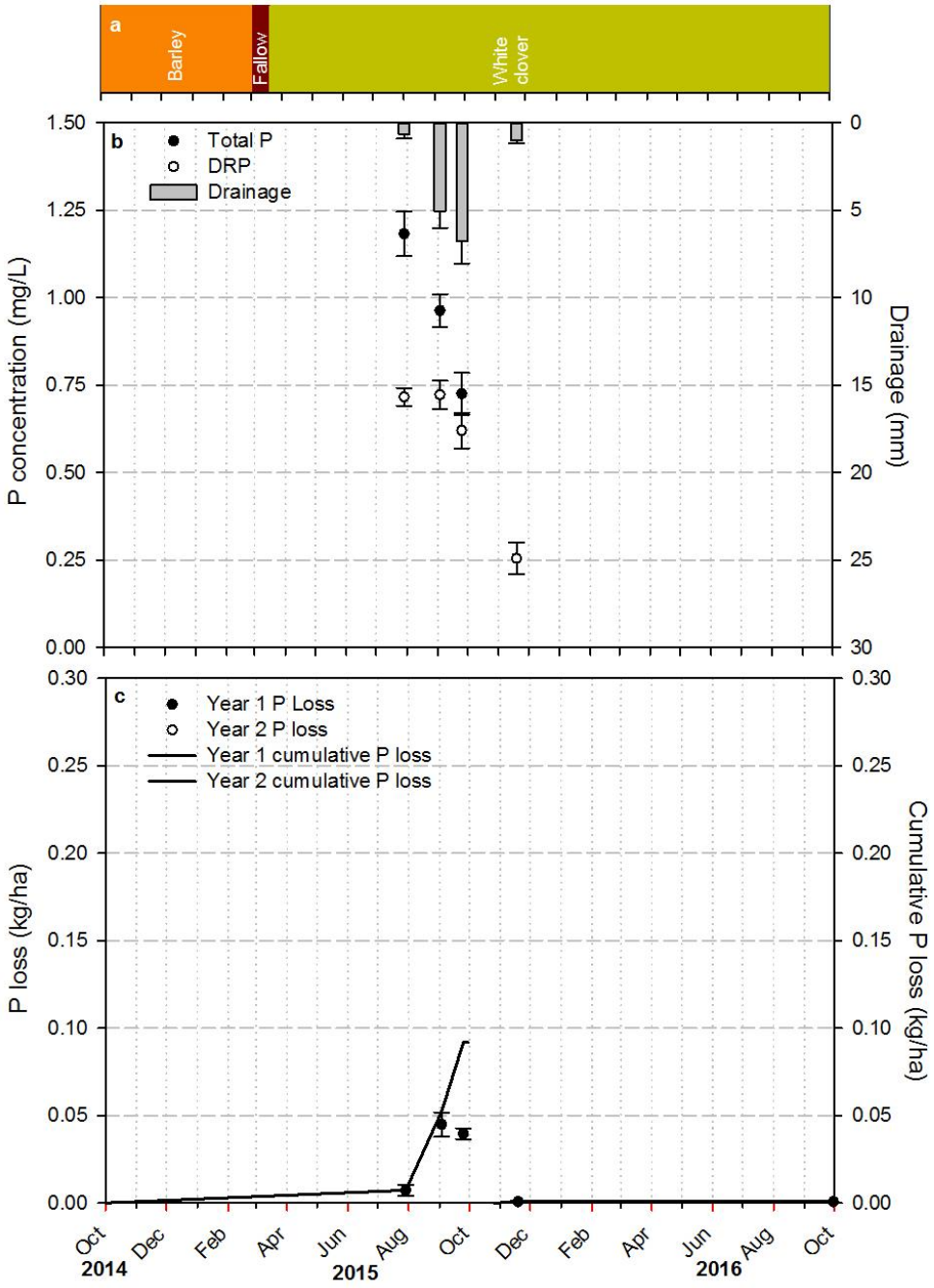

Figure 13. Summary of crop sequence (a), measured drainage and P concentrations (total P and DRP) in drainage (b) and measured system losses of total P in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September (c) Site 2 — Canterbury. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: Total P: 0.02 mg/L; DRP: 0.001 mg/L. Fluxmeters were installed on 22 September 2014.

3.3 Site 3 — Canterbury

3.3.1 Background site and crop management history

Site 3 is located near Southbridge on a mixed cropping and livestock grazing enterprise. Soil type is a Templeton loam. Fluxmeters were installed at the site in September 2014 into an established ryegrass seed crop sown in March 2014. Key site characteristics are described in Table 6.

Table 6. Summary of key farm and site characteristics, Site 3 — Canterbury.

Location	Southbridge
Farming system	Mixed cropping, livestock grazing
Topography	Flat
Soil type	Templeton loam
Key soil characteristics[1]	Soil order: Typic immature pallic Texture: Loam over clay Topsoil bulk density: 1.22 g/cm^3 Subsoil bulk density: 1.42 g/cm^3 Drainage class: Moderately well drained N leaching vulnerability: Low
Previous land use history	Arable cropping for past 5 years
Fluxmeter installation date	24 September 2014
Irrigation infrastructure	Roto-Rainer

[1]A full description of the Templeton loam is available online at https://smap.landcareresearch.co.nz/home. Listed characteristics are taken from S-MAP factsheets and are not based on measured site values.

Since installation of the fluxmeters there have been four crops including ryegrass seed, ryegrass pasture, process beans, forage oats and kale (the current crop) (Table 7). The ryegrass seed crop was harvested in January 2015 and the site was rotationally grazed by ewes and lambs until early November 2015. The site was planted to process beans in December 2015 and harvested in March 2016. Forage oats was then planted in late March for winter grazing. Grazing was completed in early September and the site subsequently planted with kale (the current crop) in late September. Respective N and P inputs have totalled 152 kg N/ha and 0 kg P/ha (ryegrass seed), 28 kg N/ha and 0 kg P/ha (ryegrass pasture), 104 kg N/ha and 30 kg P/ha (process beans), 28 kg N/ha and 0 kg P/ha (forage oats) and 46 kg N/ha and 0 kg P/ha (kale) (Table 7).

Table 7. Summary of crop management practices since fluxmeter installation (24 September 2014), Site 3 — Canterbury.

Crop management practices	Sequence 1 — Ryegrass seed	Sequence 2 — Ryegrass grazing	Sequence 3 — Beans	Sequence 4 — Forage oats	Sequence 5 — Kale
Variety	'Perun'	'Perun'	'Stanley'	White forage oats	Food processing variety
Planting population	15 kg seed/ha	15 kg seed/ha	374,000 seeds/ha	80 kg seed/ha	2.3 kg/ha
Planting date	27 March 2014	27 March 2014	26 December 2015	26 March 2016	20 September 2016
Harvest date[1]	23 January 2015[3]	30 October 2015[4]	18 March 2016	3 September 2016	Current crop
Cultivation practices	Not available	None	Grubber followed by press	Direct drill	Grubbed x3, rolled, grubbed & rolled
Fertiliser practices (product)[2]	180 kg/ha Urea (S) 150 kg/ha Urea (S)	60 kg/ha Urea (S)	300 kg/ha Crop 20 (B) 100 kg/ha Urea (B)	60 kg/ha Urea (S)	100 kg/ha Urea (S)
Summed N and P (elemental)	N = 152 kg/ha P = 0 kg/ha	N = 28 kg/ha P = 0 kg/ha	N = 77 kg/ha P = 30 kg/ha	N = 28 kg/ha P = 0 kg/ha	N=46 kg/ha P= 0 kg/ha
Stock type	Sheep	Sheep	-	Sheep	-
Stock density	123 sheep/ha	72 sheep/ha	-	124 hoggets/ha	-
Additional stock information	Site grazed by ewes and lambs in October	Site grazed by ewes in February and March Site grazed by store lambs in July and August Site grazed by ewes and spring lambs in September Site grazed by ewes and lambs in November	-	Sheep were break fed from late July to early September and over the fluxmeter units for 12 days from early August	-

[1]Commercial harvest date. [2]B = base application, P = planting application, S= side dressing application(s). [3]The site was grazed rotationally following harvest of the seed. [4]Reflects the date the ryegrass was sprayed off.

3.3.2 General weather conditions

Year 1 (1 October 2014 to 30 September 2015)

Rainfall for the Year 1 period was 547 mm, 11% below the long-term average for the region (616 mm) (Figure 14a). Rainfall for the winter and early spring period (June to September 2015) was 238 mm, comparable with the long-term average (235 mm). Mean air temperature for the 12 month period was 11.0°C, comparable than the long-term average (11.2°C) (Figure 14b) while solar radiation totalled 5140 MJ/m^2, also comparable with the long-term average of 4986 MJ/m^2 (Figure 14c)

Year 2 (1 October 2015 to 30 September 2016)

Rainfall and mean air temperature for the Year 2 period was 442 mm, 28% below the long-term average for the region (616 mm) (Figure 14a). The winter and early spring period (June to September) was particularly dry with only 114 mm rainfall recorded, 46% less than the long-term average for this period (213 mm). Mean air temperature for the 12 month period was 11.6°C, slightly warmer than the long-term average (Figure 14b) while solar radiation totalled 5141 MJ/m^2, comparable with the long-term average (Figure 14c).

3.3.3 Soil nitrogen and phosphorus levels

Soil samples for N and P fertility analyses were taken during installation of the fluxmeters in September 2014, in January 2016 (3 weeks following sowing of the bean crop) and in April 2016 (1 week after sowing of the forage oats crop).

Mineral N (0–100 cm)

Samples taken in September 2014 had low concentrations of mineral N (36 kg N/ha) while concentrations for samples taken in January and April 2016 were high (469 and 321 kg N/ha respectively) (Figure 15a). The very high concentrations observed for the January 2016 samples were consistent with the application of fertiliser N at planting (samples were taken after this application) in conjunction with recently mineralised N from the previous ryegrass crop (the site had been under pasture for the previous 2 years). For all sampling occasions, nitrate-N was the predominant form of mineral N (74–97%).

AMN (0–100 cm)

AMN concentrations were moderate to high for all sampling occasions (169–225 kg N/ha) and reflected elevated levels of potential mineralisable N (Figure 15a). Concentrations were consistent for samples taken following conversion of long-term pasture to cropping (Table 7).

Olsen P (0–20 cm)

Olsen P concentrations were low for the September 2014 samples (18 mg/L) and moderate for those taken in January and April 2016 (25–30 mg/L). These concentrations were slightly below the normal concentrations suggested for ryegrass (20–30 mg/L) and bean production (35–75 mg/L) but within the optimum range for forage oats production (Figure 15b).

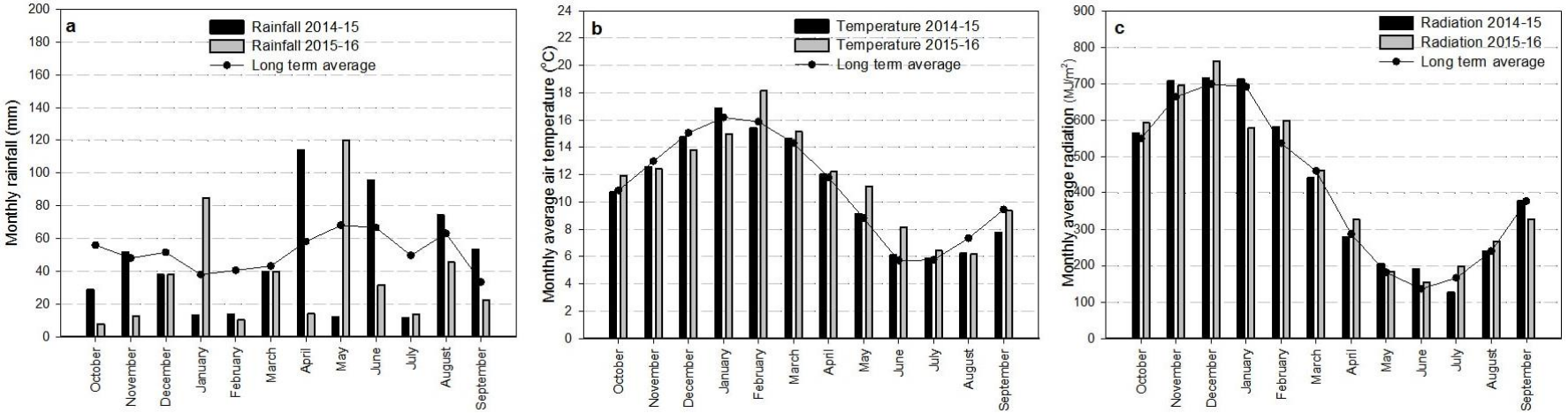

Figure 14. Monthly (a) rainfall (mm), (b) average air temperature (°C) and average solar radiation (MJ/m^2) for 1 October 2014 to 30 September 2016 at Leeston (rainfall; NIWA Station 39066), Chertsey (temperature; NIWA Station 39661) and Lincoln (radiation; NIWA Station 17603). Long-term climate data are presented for the Lincoln (rainfall and radiation, 2001–14) and Ashburton stations (temperature, 2006–14, NIWA Station 26170).

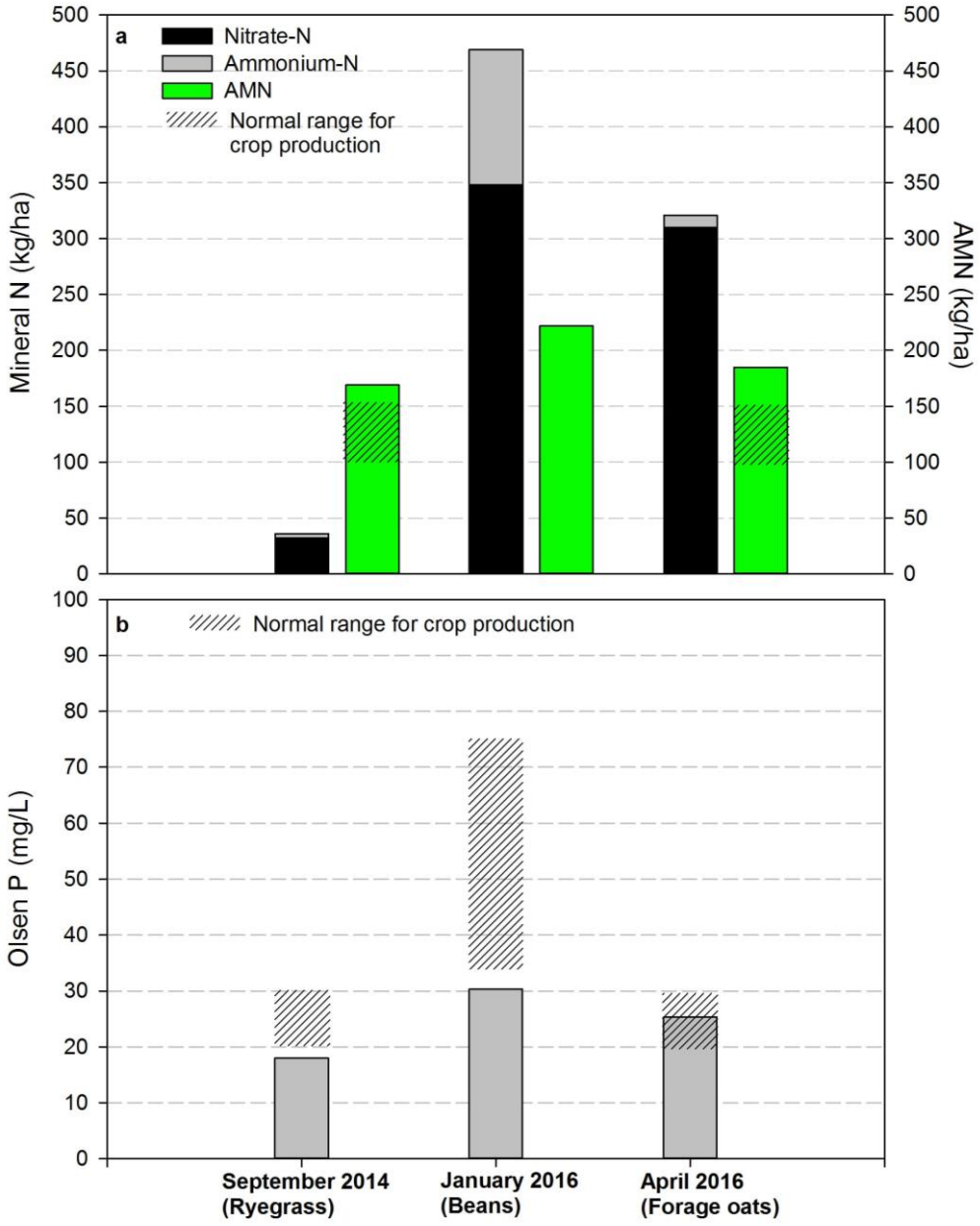

Figure 15. Soil mineral N and AMN (0–100 cm depth) (a) and Olsen P (0–20 cm depth) (b) at Site 3 — Canterbury for samples taken in September 2014, January 2016 and April 2016. Normal ranges suggested for crop production are provided by Hill Laboratories (http://www.hill-laboratories.com/page/pageid/2145845703/Crop_Guides).

3.3.4 Soil water balance

Year 1 (1 October 2014 to 30 September 2015)

The soil water balance for Site 3 is shown in Figure 16. Rainfall and irrigation for Year 1 totalled 547 mm and 450 mm respectively. There was only one rainfall event over 50 mm which occurred in late April 2015 (57 mm over 3 days). Irrigation was applied at 50 mm per application between late October 2014 and mid-February 2015.

Modelled soil water contents at all depths tended to increase from April 2015 and remained at elevated contents from mid-August 2015 onwards. Fluxmeter drainage samples were collected during this period.

Year 2 (1 October 2015 to 30 September 2016)

Rainfall and irrigation for the Year 2 period totalled 442 mm and 270 mm respectively. The largest rainfall event was in late May 2016 (70 mm recorded over 4 days) (Figure 16). There were six irrigation applications of 45 mm between early December 2015 and mid-March 2016.

Modelled soil water contents decreased at all depths from October onwards before increasing to elevated levels in late December in response to a period of consistent rainfall and large irrigation volumes. Four drainage samples were collected over the Year 2 period, one in January, one in February and two in June.

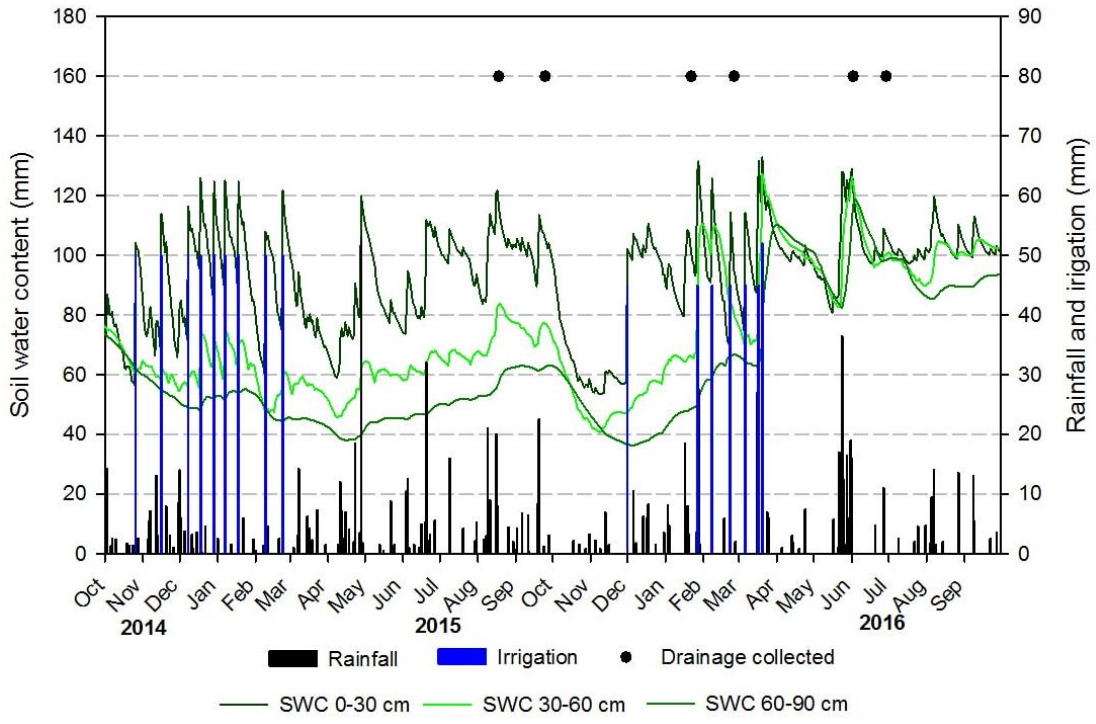

Figure 16. Summary of daily rainfall, irrigation, modelled soil water content (0–30 cm, 30–60 cm and 60–90 cm) and predicted drainage from 1 July 2014, Site 3 — Canterbury. Fluxmeter units were installed on 24 September 2014.

3.3.5 Losses of N and P in drainage water

Year 1 (1 October 2014 to 30 September 2015)

Drainage samples were collected on two occasions in the first year following installation of the fluxmeters (Figure 17b). Total drainage volume was 8 mm.

Nitrate-N and ammonium-N concentrations in drainage for this period averaged 7.8 mg/L and 1.0 mg/L respectively (Figure 17b). Due to low N concentrations and low drainage volumes, measured mineral N losses from the system were minimal totalling 0.9 kg N/ha (Figure 17c) with the majority of this N lost as nitrate-N (0.8 kg N/ha).

Total P and DRP concentrations averaged 0.22 mg/L and 0.15 mg/L respectively (Figure 18b). Measured P losses from the system over this period were minimal (< 0.1 kg P/ha; Figure 18c).

Year 2 (1 October 2015 to 30 September 2016)

Drainage samples were collected on four occasions in the second year following installation of the fluxmeters. Total drainage volume was 39 mm.

Nitrate-N and ammonium-N concentrations in drainage for this period averaged 10.5 mg/L and 0.5 mg/L respectively (Figure 17b). Nitrate-N concentrations were highest in the June 2016 samples (17.6 mg/L). Despite higher drainage volumes and nitrate-N concentrations than in Year 1, measured mineral losses remained low (3.9 kg N/ha; Figure 17c).

Total P and DRP concentrations averaged 0.20 mg/L and 0.17 mg/L respectively (Figure 18b). Measured P losses from the system over this period were minimal (0.07 kg P/ha; Figure 18c).

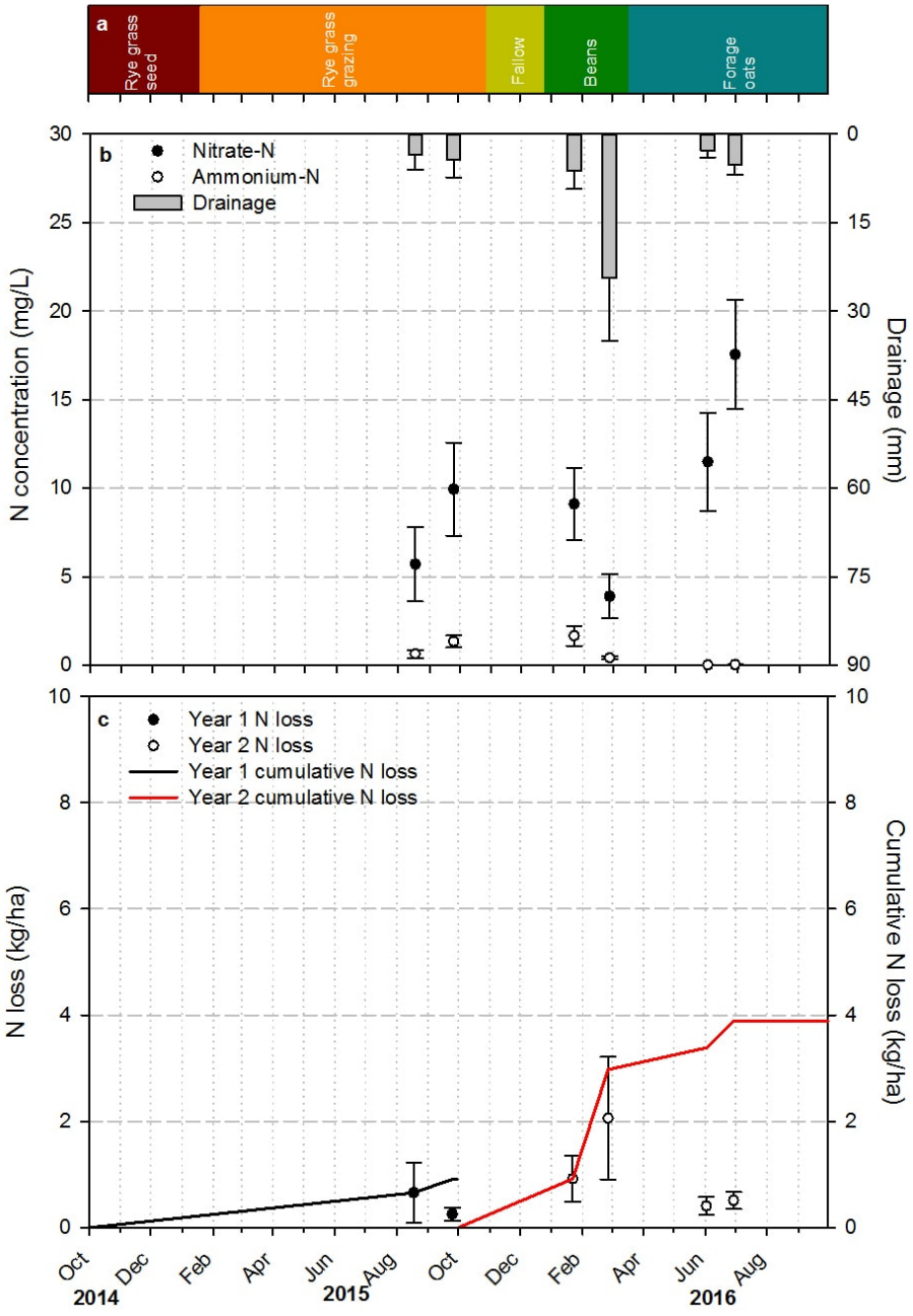

Figure 17. Summary of crop sequence (a), measured drainage and inorganic N concentrations (nitrate-N and ammonium-N) in drainage (b) and measured system losses of inorganic N in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) (c) Site 3 — Canterbury. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: nitrate-N: 0.02 mg/L; ammonium-N: 0.01 mg/L. Fluxmeters were installed on 24 September 2014.

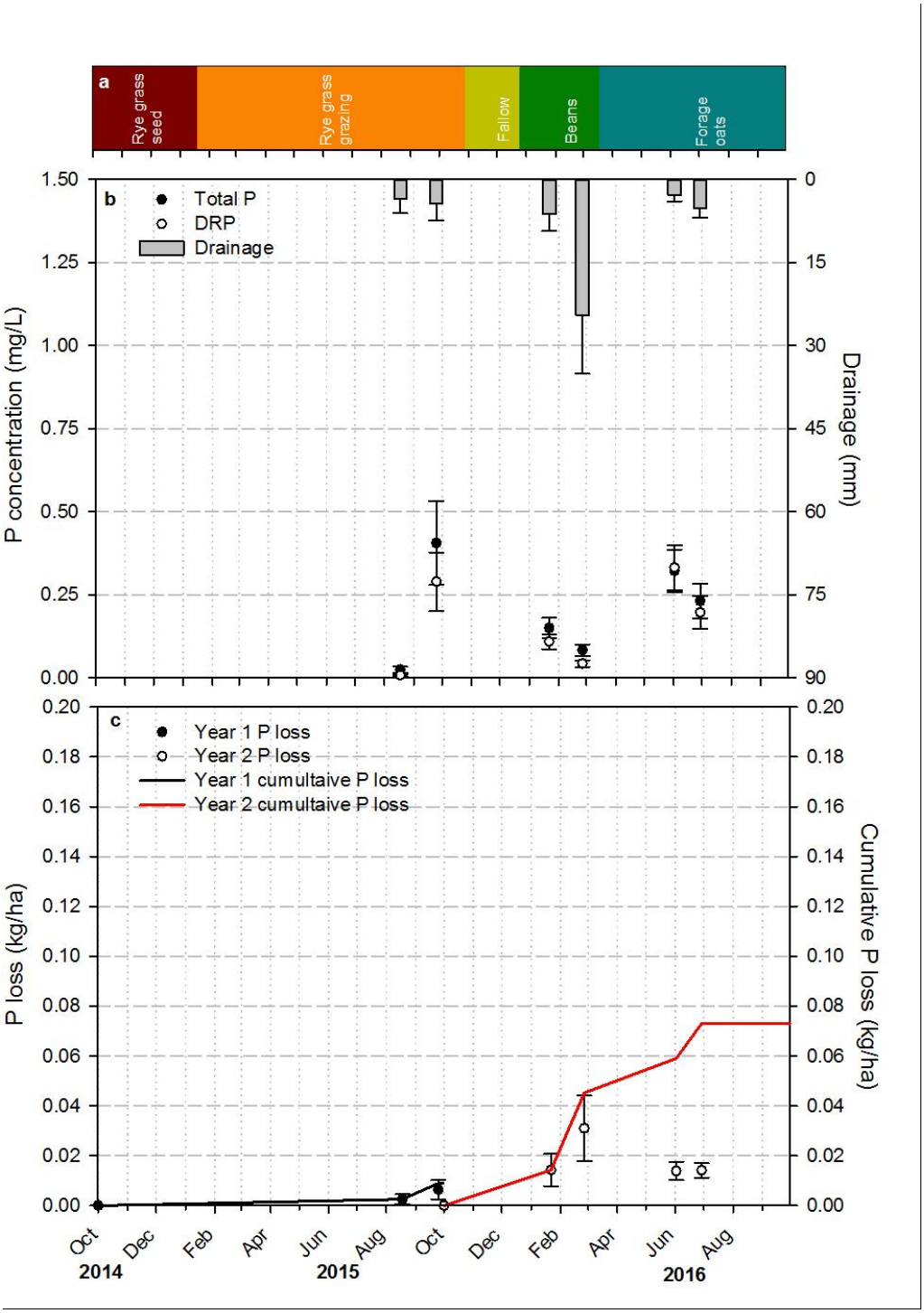

Figure 18. Summary of crop sequence (a), measured drainage and P concentrations (total P and DRP) in drainage (b) and measured system losses of total P in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) (c) Site 3 — Canterbury. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: Total P: 0.02 mg/L; DRP: 0.001 mg/L. Fluxmeters were installed on 24 September 2014.

3.4 Site 4 — Manawatu

3.4.1 Background site and crop management history

Site 4 is located near Levin on an intensive vegetable cropping enterprise. Soil type is a Shannon silt loam. Fluxmeters were installed at the site in October 2014. Key site characteristics are described in Table 8.

Table 8. Summary of key farm and site characteristics, Site 4 — Manawatu.

Location	Levin
Farming system	Intensive vegetable production
Topography	Flat
Soil type	Shannon silt loam
Key soil characteristics[1]	Soil order: Mottled argillic pallic Texture: Silty loam Topsoil bulk density: 1.22 g/cm^3 Subsoil bulk density: 1.42 g/cm^3 Drainage class: Moderate over slow N leaching vulnerability: Low
Previous land use history	Intensive vegetable production for past 7 years.
Fluxmeter installation date	20 October 2014
Irrigation infrastructure	Lateral

[1]A full description of the Shannon silt loam is available online at https://smap.landcareresearch.co.nz/home. Listed characteristics are taken from S-MAP factsheets and are not based on measured site values.

Since installation of the fluxmeters there have been six crops grown. The first crop (lettuce 2014) was planted in October 2014 and harvested 2 months later in December. Spinach was subsequently planted in February 2015 (harvested in April), May 2015 (harvested in September 2015) and July 2015 (harvested in September 2015). Following harvest of the third spinach crop, the site remained fallow until December before being planted to lettuce (lettuce 2015) which was harvested in February 2016. A cabbage crop was planted in March 2016 and harvested in July 2016. The site is currently fallow and is due to be planted to zucchinis in October 2016. Respective N and P inputs have totalled 200 kg N/ha and 208 kg P/ha (lettuce 2014), 81 kg N/ha and 0 kg P/ha (spinach 1), 101 kg N/ha and 16 kg P/ha (spinach 2), 62 kg N/ha and 26 kg P/ha (spinach 3), 91 kg N/ha and 40 kg P/ha (lettuce 2015) and 191 kg N/ha and 46 kg P/ha (cabbage) (Table 9).

Table 9. Summary of crop management practices since fluxmeter installation (20 October 2014), Site 4 — Manawatu.

Crop management practices	Sequence 1 — Lettuce	Sequence 2 — Spinach	Sequence 3 — Spinach	Sequence 4 — Spinach	Sequence 5 — Lettuce	Sequence 6 — Cabbage
Variety	'Casino'	'Twilight'	'Blackglove'	'Manatee'	'Casino'	'Hyb 228'
Planting population	43,500 plants/ha	650,000 plants/ha	650,000 plants/ha	650,000 plants/ha	43,860 plants/ha	32,890 plants/ha
Planting date	23 October 2014	18 February 2015[1]	27 May 2015[1]	2 July 2015[2]	30 December 2015	9 March 2016
Harvest date[3]	24 December 2014	1 April 2015	10 September 2015	28 September 2015	11 February 2016[4]	21 July 2016
Cultivation practices	Chisel plough and power harrow	Chisel plough and power harrow followed by bed moulding	Rotary hoe	Rotary hoe	Chisel plough and power harrow followed by bed moulding	Chisel plough and power harrow followed by bed moulding
Fertiliser practices (product)[5]	2.2 t/ha Aglime (B) 2 t/ha SSP (B) 560 kg/ha CropStart (S) 490 kg/ha CAN (S)[6]	300 kg/ha CAN (S)	313 kg/ha CropStart (S) 234 kg/ha CAN (S)	519 kg/ha CropStart (S)	760 kg/ha Nitrophoska (B)	387 kg/ha Nitrophoska (B) 153 kg/ha Kieserite (B) 517 kg/ha Rustica blue (S) 309 kg/ha CAN (S)
Summed N and P (elemental)	N = 200 kg/ha P = 208 kg/ha	N = 81 kg/ha P = 0 kg/ha	N = 101 kg/ha P = 16 kg/ha	N = 62 kg/ha P = 26 kg/ha	N = 91 kg/ha P = 40 kg/ha	N = 191 kg/ha P = 46 kg/ha
Stock type	No stock	No stock	No stock	No stock	No stock	No stock
Stock density	-	-	-		-	-
Additional stock information	-	-	-		-	-

[1]Crop was only established over half the experimental area. [2]Crop was established over the second half of the experimental area. [3]Commercial harvest date. [4]40% of the crop was selectively harvested on this date with remainder harvested on 17 February 2016. [5]B = base application, P = planting application, S= side dressing application(s). [6]Split over two applications between November and December 2014.

3.4.2 General weather conditions

Year 1 (1 October 2014 to 30 September 2015)

Rainfall and mean air temperature for the Year 1 period was 1046 mm and 13.1°C. This was comparable with the long-term average for the region (995 mm and 13.2°C respectively) (Figure 19a and b). The mid-autumn to early winter period (1 April to 30 June 2015) was particularly wet, with close to twice the amount of rainfall (489 mm) compared with the long-term average for the same period (256 mm).

Solar radiation for the 12 month period totalled 5030 MJ/m^2, comparable to the long-term average of 4949 MJ/m^2 (Figure 19c).

Year 2 (1 October 2015 to 30 September 2016)

Rainfall for the Year 2 period totalled 1018 mm, comparable to the long-term average for the region (Figure 19a) while air temperature averaged 14.0°C, warmer than the long-term average (Figure 19b). Solar radiation totalled 4994 MJ/m^2, comparable to the long-term average (Figure 19c).

3.4.3 Soil nitrogen and phosphorus fertility levels

Soil samples for N and P fertility analyses were taken during installation of the fluxmeters in September 2014, and in May 2015, October 2015 and March 2016 prior to planting of respective spinach, lettuce and cabbage crops.

Mineral N (0–100 cm)

Samples taken in September 2014 had low concentrations of mineral N (36 kg N/ha), whereas concentrations for samples taken in May and October 2015 and March 2016 were high (327, 162 and 154 kg N/ha respectively) (Figure 20a). For all sampling occasions the predominant form of mineral N was nitrate-N (66–81%). High concentrations of mineral N in the May and October 2015 and March 2016 samples reflect the application of N fertilisers to the previous lettuce and spinach crops (Table 9) which were above expected removal rates.

AMN (0–100 cm)

AMN concentrations were low to moderate across the four sampling dates (65–109 kg/ha; Figure 20a). Concentrations were within normal ranges suggested for lettuce, spinach and cabbage production (100–150 kg N/ha) (September 2014, May 2015 and March 2016 samples) but below normal levels for the October 2015 samples.

Olsen P (0–20 cm)

Olsen P concentrations were high for both all sampling occasions (111–149 mg/L) and well above normal concentrations suggested for lettuce and spinach (35–90 mg/L) and cabbage production (35–70 mg/L) (Figure 20b).

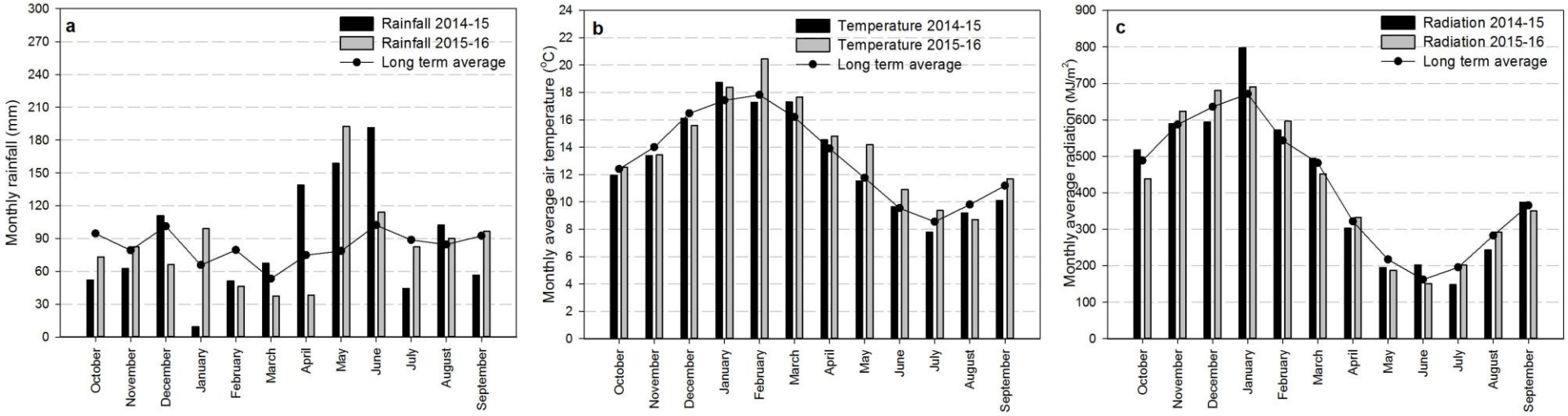

Figure 19. Monthly (a) rainfall (mm), (b) average air temperature (°C) and average solar radiation (MJ/m^2) for 1 October 2014 to 30 September 2016 at Levin (NIWA Station 3275). Long-term climate data (2001–14) are presented for the Levin station.

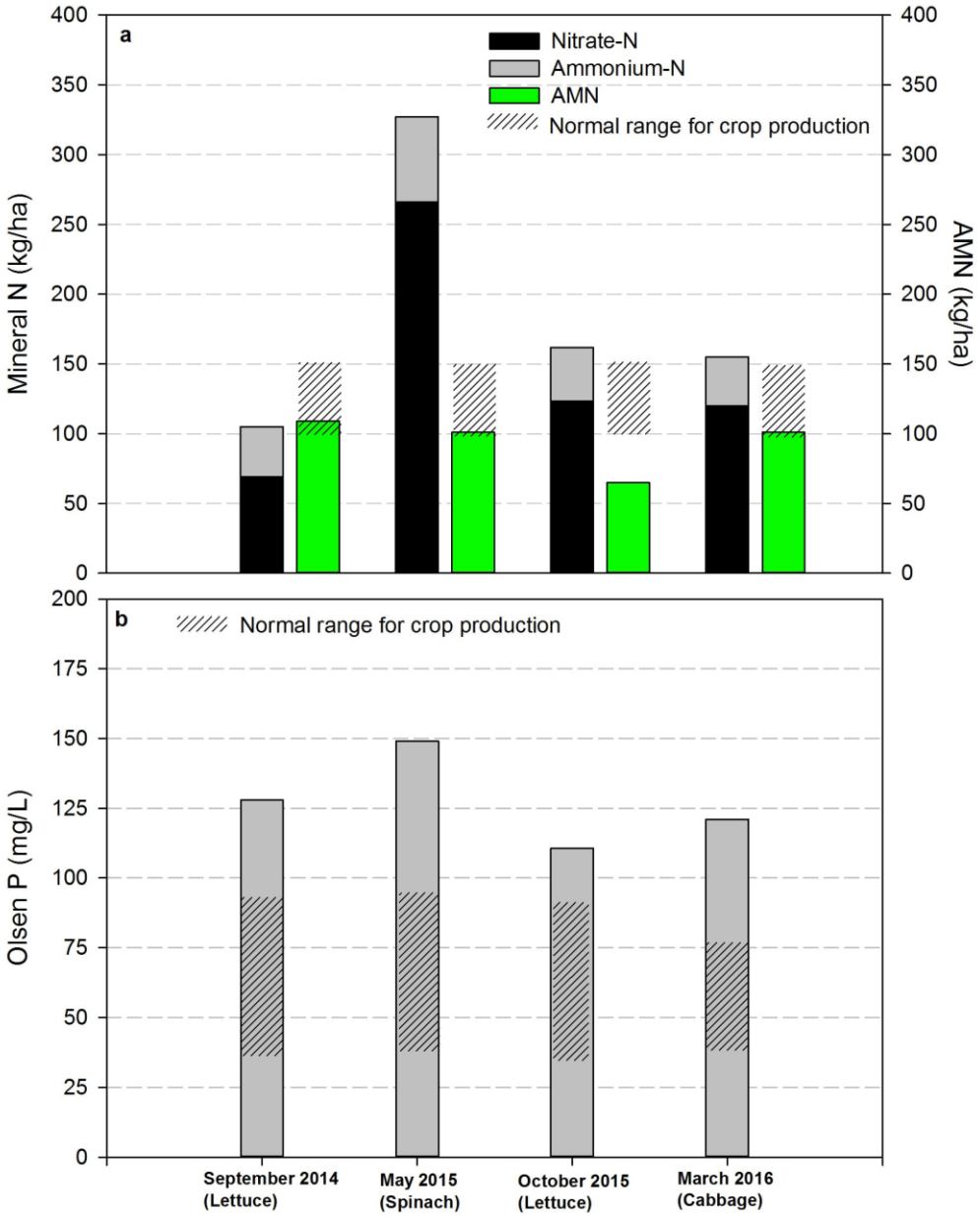

Figure 20. Soil mineral N and AMN (0–100 cm depth) (a) and Olsen P (0–20 cm depth) (b) at Site 4 — Manawatu for samples taken in September 2014, May 2015, October 2015 and March 2016. Normal ranges suggested for crop production are provided by Hill Laboratories (http://www.hill-laboratories.com/page/pageid/2145845703/Crop_Guides).

3.4.4 Soil water balance

Year 1 (1 October 2014 to 30 September 2015)

The soil water balance for Site 4 is shown in Figure 21. Rainfall and irrigation for the Year 1 period totalled 1046 mm and 22 mm respectively. The mid-autumn through to early winter period was particularly wet and there were a number of significant rainfall events including 93 mm over 6 days in early April, 111 mm over 5 days in mid-May and 97 mm over 2 days in mid-June. The range in individual irrigation application volumes was 5 to 6 mm.

Modelled soil water contents for all depths remained elevated for the duration of the monitoring period (> 110 mm). This was consistent with the collection of drainage samples, which occurred on a regular basis throughout the year.

Year 2 (1 October 2015 to 30 September 2016)

Rainfall and irrigation for the Year 2 period totalled 1018 mm and 40 mm respectively. The wettest period occurred between mid to late May when 116 mm was recorded over a 9 day period (Figure 21). There were two irrigation applications of 20 mm between late January and early February 2016.

As in Year 1, modelled soil water contents for all depths tended to decrease between December and February although on the whole remained elevated for the duration of the monitoring period (> 110 mm). Drainage samples were collected on a regular basis throughout the year (eight in total).

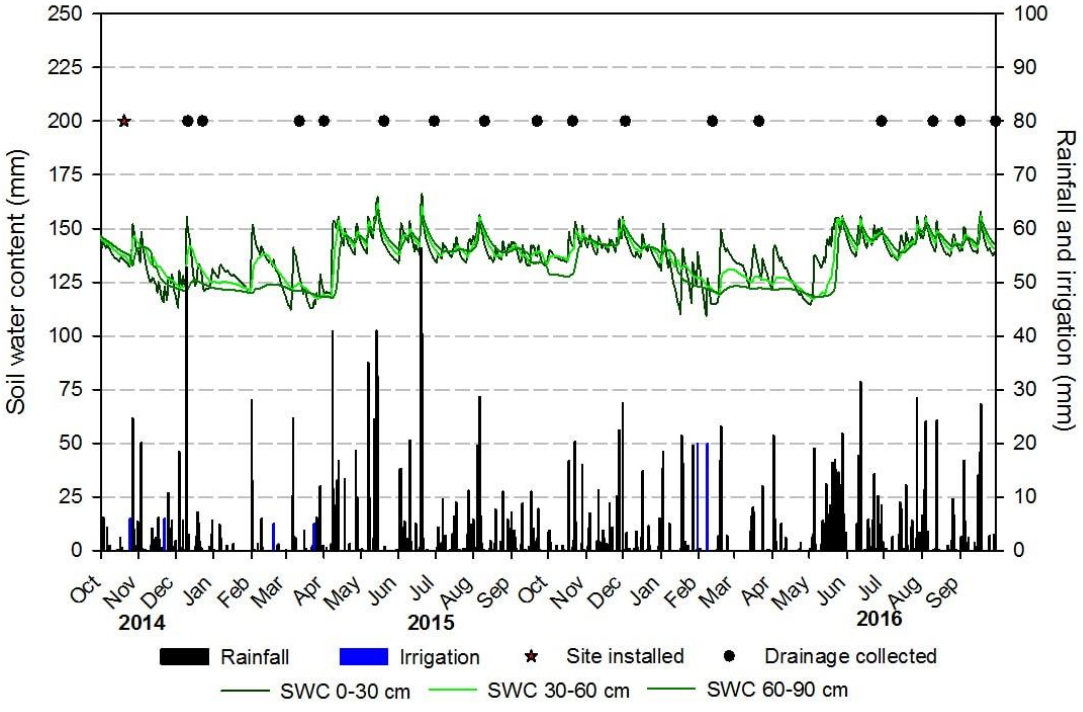

Figure 21. Summary of daily rainfall, irrigation and modelled soil water content (0–30 cm, 30–60 cm and 60–90 cm) from 1 October 2014, Site 4 — Manawatu.

3.4.5 Losses of N and P in drainage water

Year 1 (1 October 2014 to 30 September 2015)

Drainage samples were collected on eight occasions in the first year following installation of the fluxmeters. Total drainage volume was 339 mm.

Nitrate-N and ammonium-N concentrations in drainage for this period averaged 50.0 mg/L and 1.5 mg/L respectively (Figure 22b). Nitrate-N concentrations tended to increase over time and peaked at 75.0 mg/L in late June 2015, while ammonium-N concentrations remained comparatively low (< 4.6 mg/L). Measured mineral N losses from the system totalled 212 kg N/ha (Figure 22c) with the majority of N lost as nitrate-N (210 kg N/ha). The high N losses observed between May and September 2015 reflected the combination of high nitrate-N concentrations in drainage and increased drainage volumes.

Total P and DRP concentrations averaged 0.29 mg/L and 0.21 mg/L respectively (Figure 23b). Measured P losses from the system were low, totalling 0.56 kg P/ha with DRP loss accounting for 0.42 kg P/ha (Figure 23c). The observed decline in the concentration difference between total P and DRP over the monitoring period suggests a net decrease in the transfer of dissolved organic P and/or sediment bounds P forms (> 0.45 µm). This most likely reflects a soil 'settling effect' following installation of the fluxmeter units.

Year 2 (1 October 2015 to 30 September 2016)

Drainage samples were collected on eight occasions in the second year following installation of the fluxmeters. Total drainage volume was 339 mm, the same as in Year 1.

Nitrate-N and ammonium-N concentrations in drainage for this period averaged 37.7 mg/L and 0.02 mg/L respectively (Figure 22b). Nitrate concentrations decreased from 56.1 mg/L in early December 2015 to 19.9 mg/L in late September 2016. Measured mineral N losses from the system totalled 118 kg N/ha (Figure 22c) with N lost almost entirely as nitrate-N.

Total P and DRP concentrations averaged 0.14 mg/L and 0.07 mg/L respectively (Figure 23b). Measured P losses from the system were low (0.27 kg P/ha; Figure 23c).

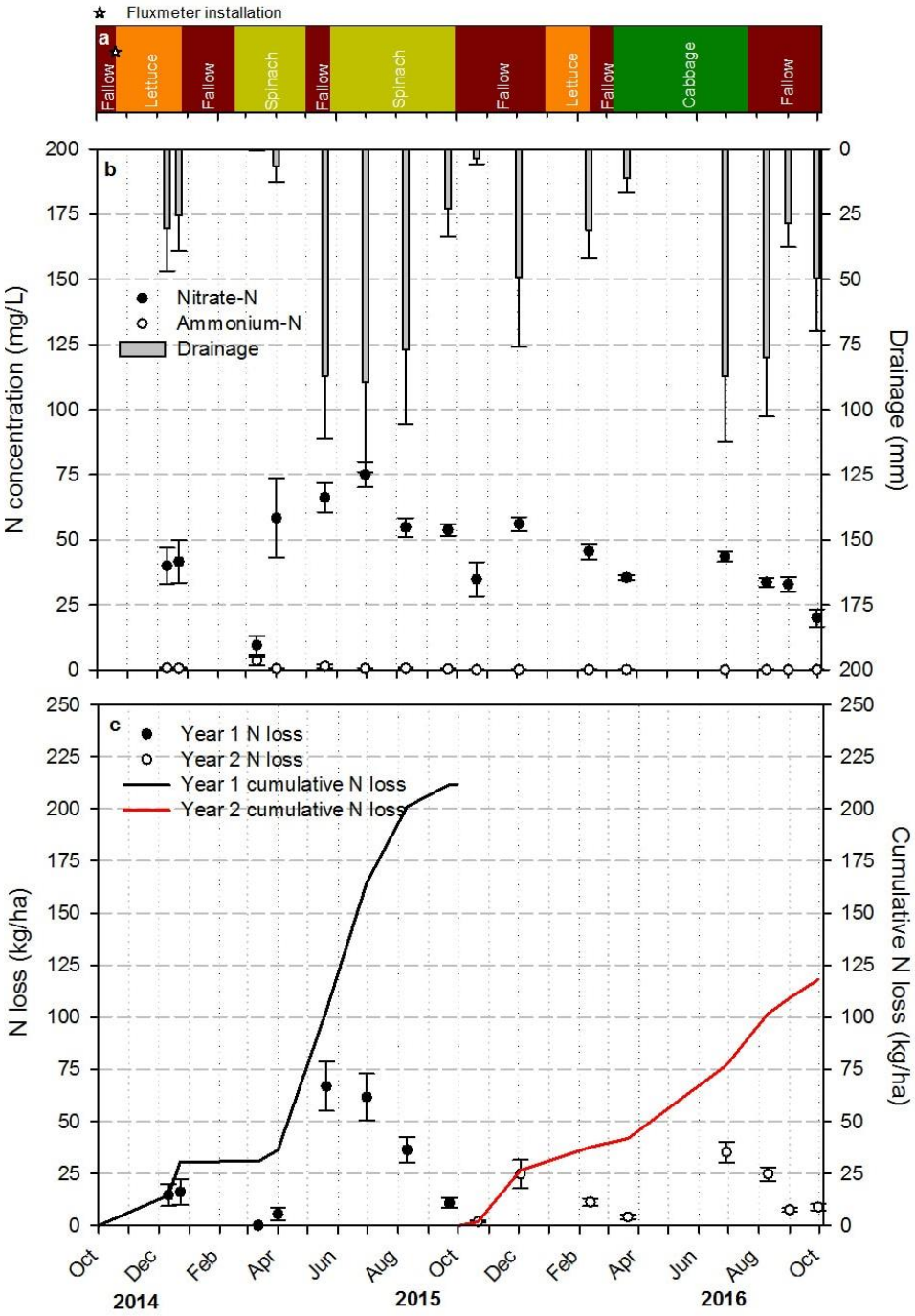

Figure 22. Summary of crop sequence (a), measured drainage and inorganic N concentrations (nitrate-N and ammonium-N) in drainage (b) and measured system losses of inorganic N in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) (c) Site 4 — Manawatu. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: nitrate-N: 0.02 mg/L; ammonium-N: 0.01 mg/L.

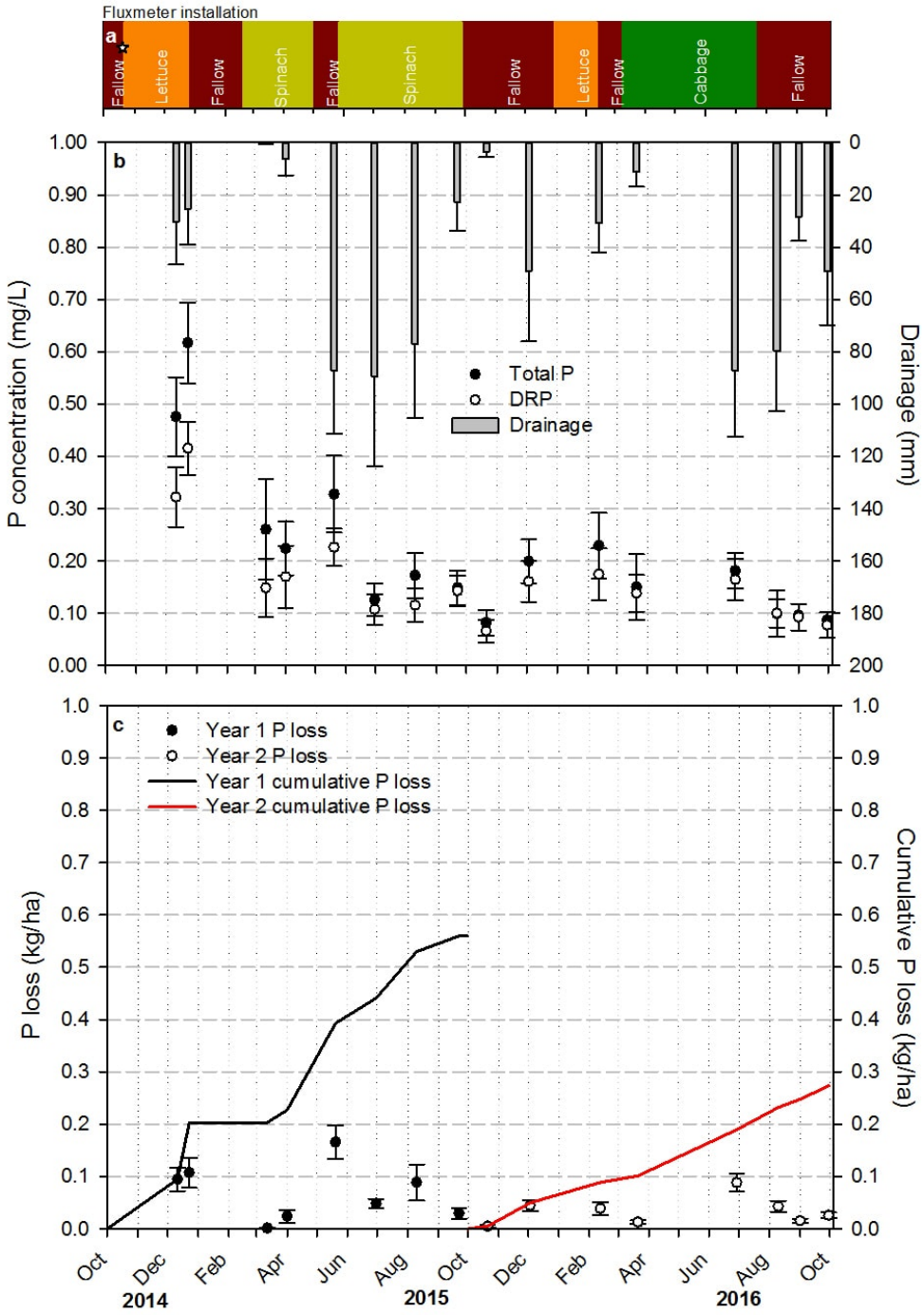

Figure 23. Summary of crop sequence (a), measured drainage and P concentrations (total P and DRP) in drainage (b) and measured system losses of total P in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) (c) Site 4 — Manawatu. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: Total P: 0.02 mg/L; DRP: 0.001 mg/L. Fluxmeters were installed on 24 September 2014.

3.5 Site 5 – Manawatu

3.5.1 Background site and crop management history

Site 5 is located near Bulls on a mixed cropping and livestock grazing enterprise. Soil type is a Pukepuke sandy loam. Fluxmeters were installed at the site in September 2014. Key site characteristics are described in Table 10.

Table 10. Summary of key farm and site characteristics, Site 5 — Manawatu.

Location	Bulls
Farming system	Mixed cropping, livestock grazing
Topography	Flat
Soil type	Pukepuke sandy loam
Key soil characteristics[1]	Soil order: Typic sandy gley Texture: Sandy loam Topsoil bulk density: 1.18 g/cm^3 Subsoil bulk density: 1.38 g/cm^3 Drainage class: Poorly drained N leaching vulnerability: Very low
Previous land use history	Converted from pine plantation to mixed cropping and livestock grazing in 2009.
Fluxmeter installation date	29 September 2014
Irrigation infrastructure	Centre pivot

[1]A full description of the Pukepuke sandy loam is available online at https://smap.landcareresearch.co.nz/home. Listed characteristics are taken from S-MAP factsheets and are not based on measured site values.

Since installation of the fluxmeters there have been three crops including maize, an oats cover crop and fodder beet (Table 11). The site was sown to maize in October 2014, harvested for grain in May 2015 and then left fallow for the winter before being sown to oats in late August 2015. The oats crop was planted to reduce wind erosion before establishment of a fodder beet crop in November 2015. The fodder beet was progressively harvested between mid-June and late July for use as winter feed. The site was subsequently planted to forage oats (the current crop) in late September 2016. Respective N and P inputs have totalled 189 kg N/ha and 42 kg P/ha (maize), 158 kg N/ha and 40 kg P/ha (fodder beet) and 158 kg N/ha and 40 kg P/ha (forage oats) (Table 11). No fertiliser was applied to the oat cover crop.

Table 11. Summary of crop management practices since fluxmeter installation (29 September 2014), Site 5 — Manawatu.

Crop management practices	Sequence 1 — Maize	Sequence 2 — Oats cover crop	Sequence 3—— Fodder beet	Sequence 4 — Forage oats
Variety	P8805	'Milton'	'Enermax'	'Milton'
Planting population	95,000 plants/ha	80 kg/ha	100,000 plants/ha	130 kg seed/ha
Planting date	28 October 2014	15 August 2015	3 November 2015	27 September 2016
Harvest date[1]	1 May 2015	25 October 2015[2]	15 July 2016[3]	Current crop
Cultivation practices	Turbo chisel followed by turbo till and power harrow	Turbo chisel followed by disking and then planting	Ripped followed by rotary hoe (20 cm strips)	Turbo chisel followed by disking and then planting
Fertiliser practices (product)[4]	130 kg/ha SSP (B) 60 kg/ha KCl (B) 300 kg/ha Nitrophoska (P) 330 kg/ha Urea (S)	None	100 kg/ha DAP (P) 219 kg/ha Super10 (P) 103 kg/ha Sustain-N (P) 100 kg/ha KCl (P) 200 kg/ha MOP (P) 100 kg/ha Sustain-N (S) 80 kg/ha Urea (S) 250 kg/ha MOP (S)[5] 50 kg/ha ammonium sulphate (S)	1250 kg/ha chicken manure (B) 250 kg/ha Yara Mila (B) 170 kg/ha Super 10 (B) 130 kg/ha Coated urea (B) 70 kg/ha MOP (B) 53 kg/ha Zinc zulphate (B)
Summed N and P (elemental)	N = 189 kg/ha P = 42 kg/ha	N = 0 kg/ha P = 0 kg/ha	N = 158 kg/ha P = 40 kg/ha	N = 123 kg/ha P = 40 kg/ha
Stock type	No stock	No stock	Yearling cattle	No stock
Stock density	-	-	1 cow/ha	-
Additional stock information	-	-	Cows in field from early August to mid-September	-

[1]Commercial harvest date. [2]Reflects the date the oats cover crop was sprayed off. [3]Crop was progressively harvested between early June and mid-July 2016. [4]B = base application, P = planting application, S= side dressing application(s). [5]Split over two applications between January and February.

3.5.2 General weather conditions

Year 1 (1 October 2014 to 30 September 2015)

Rainfall for the Year 1 period was 1189 mm, 27% higher than the long-term average for the region (934 mm) (Figure 24a). The mid-autumn to early winter period (1 April to 30 June 2015) was particularly wet with close to three times the amount of rainfall (612 mm) compared to the long-term average for the same period (228 mm).

Average air temperature for the 12 month period was 13.3°C, comparable to the long-term average (13.4°C) (Figure 24b) while solar radiation totalled 5330 MJ/m^2, close to the long-term average of 5113 MJ/m^2 (Figure 24c).

Year 2 (1 October 2015 to 30 September 2016)

Rainfall for the Year 2 period totalled 933 mm, comparable to the long-term average for the region (Figure 24a). Rainfall was distributed relatively evenly over the year except for the month of May where more than three times the amount of rainfall was recorded (213 mm) compared to the long-term average for the same period (66 mm). Average air temperature over the 12 month period was 14.1°C, warmer than the long-term average (13.4°C; Figure 24b) while solar radiation totalled 5199 MJ/m^2 comparable to the long-term average for the region (5113 MJ/m^2; Figure 24c).

3.5.3 Soil nitrogen and phosphorus fertility levels

Soil samples for N and P analyses were taken following installation of the fluxmeters in September 2014, prior to planting of respective fodder beet and forage oats crops in November 2015 and September 2016.

Mineral N (0–100 cm)

Samples taken in September 2014 and September 2016 had low concentrations of mineral N (35–44 kg N/ha) with an increased proportion of mineral N present in the ammonium-N form (41–52%). In contrast, mineral concentrations were moderate for samples taken in October 2015 (126 kg N/ha) with a greater proportion present as nitrate-N (70%).

AMN (0–100 cm)

AMN concentrations were moderate (134–156 kg N/ha) for all sampling occasions and within or slightly above the normal concentrations suggested for maize, fodder beet and oats production (100–150 kg N/ha) (Figure 25a).

Olsen P (0–20 cm)

Olsen P concentrations were moderate (25–32 mg/L) and within, or close to, the normal concentrations suggested for maize (15–30 mg/L), fodder beet (20–30 mg/L) and oats (20–30 mg/L) (Figure 25b).

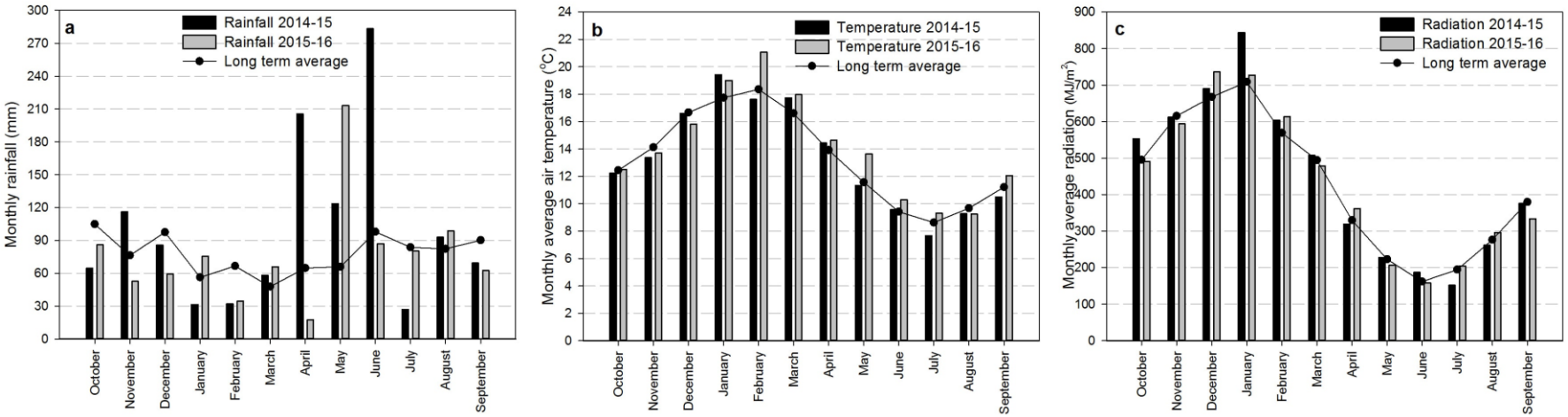

Figure 24. Monthly (a) rainfall (mm), (b) average air temperature (°C) and average solar radiation (MJ/m^2) for 1 October 2014 to 30 September 2016 at Palmerston North (NIWA Station 3243). Long-term climate data (2001–14) are presented for the Palmerston North station.

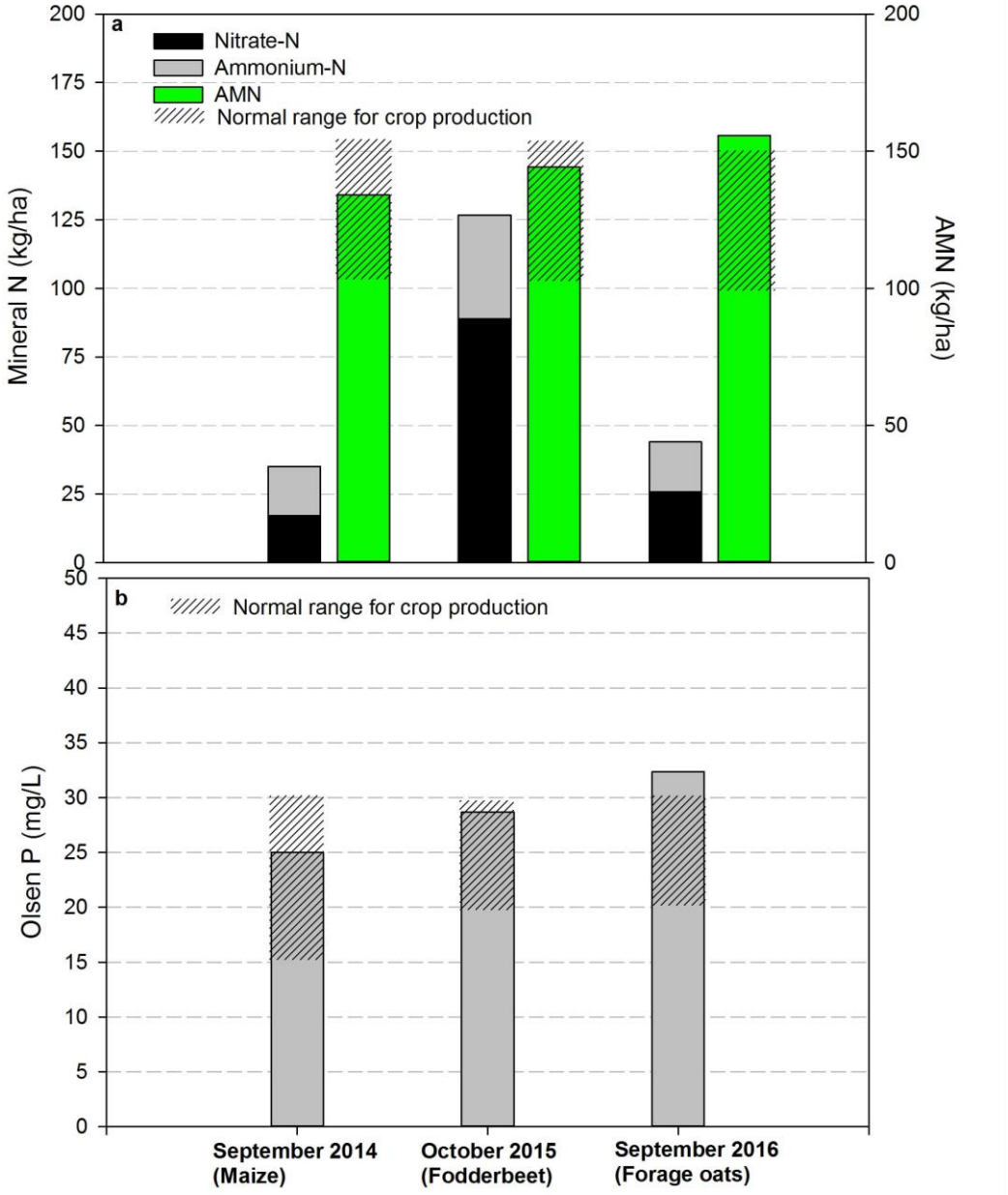

Figure 25. Soil mineral N and AMN (0–100 cm depth) (a) and Olsen P (0–20 cm depth) (b) at Site 5 — Manawatu for samples taken in September 2014, October 2015 and September 2016. Normal ranges suggested for crop production are provided by Hill Laboratories (http://www.hill-laboratories.com/page/pageid/2145845703/Crop_Guides).

3.5.4 Soil water balance

Year 1 (1 October 2014 to 30 September 2015)

The soil water balance for Site 5 is shown in Figure 26. Rainfall and irrigation for the Year 1 period totalled 1189 mm and 368 mm respectively. The mid-autumn through to early winter period (April to August 2015) was particularly wet and there were a number of significant rainfall events including 153 mm over 7 days in early April, 96 mm over 5 days in mid-May and 163 mm over 2 days in mid-June. The range in individual irrigation application volumes was 5 to 7.5 mm.

Modelled soil water contents for all depths remained elevated for the duration of the monitoring period (> 110 mm). This was consistent with drainage sample collection which occurred on a regular basis throughout the year (seven in total).

Year 2 (1 October 2015 to 30 September 2016)

Rainfall and irrigation for the Year 2 period totalled 933 mm and 410 mm respectively. Rainfall occurred on a consistent basis through this period, however the late-autumn through to early spring period (May to September 2015) was particularly wet and there were a number of significant rainfall events including 54 mm in 1 day in early May, 91 mm over 8 days in late May and 46 mm over 2 days in late August. Irrigation was applied on a daily basis between late December and mid-March at 5 mm per application.

As in Year 1, modelled soil water contents remained elevated for the duration of the monitoring period (> 100 mm) and were consistent with regular rainfall and irrigation inputs. Drainage samples (ten in total) were collected on a regular basis throughout the year.

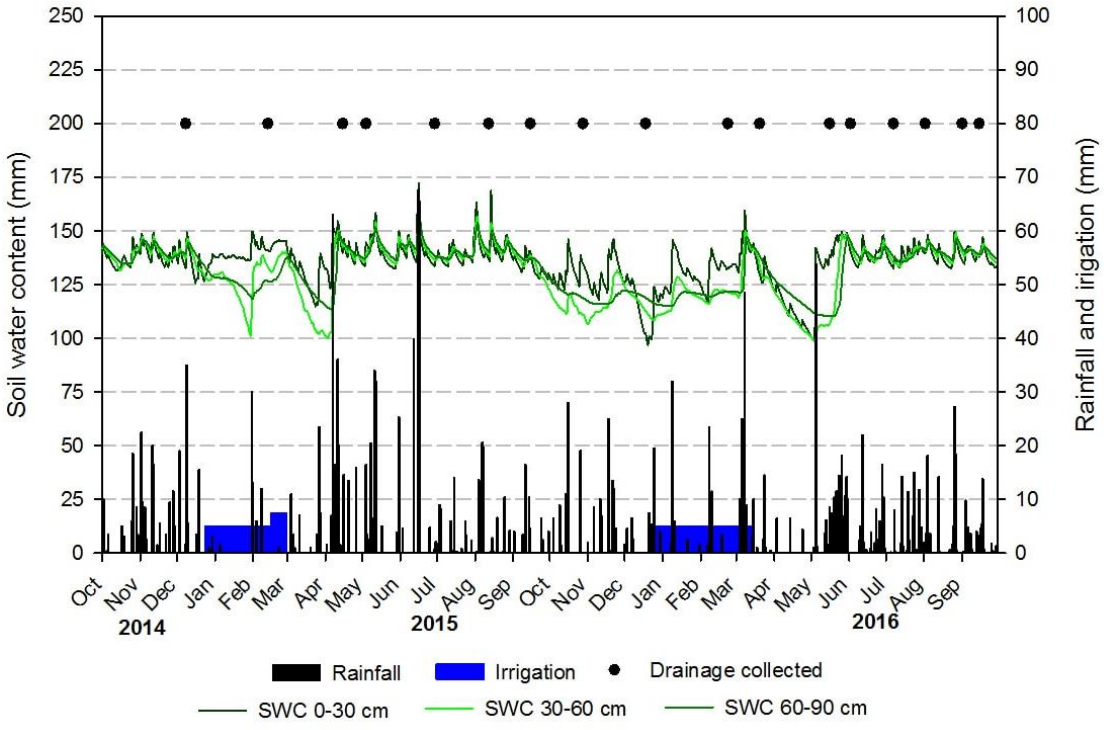

Figure 26. Summary of daily rainfall, irrigation and modelled soil water content (0–30 cm, 30–60 cm and 60–90 cm) from 1 October 2014, Site 5 — Manawatu. Fluxmeter units were installed on 29 September 2014.

3.5.5 Losses of N and P in drainage water

Year 1 (1 October 2014 to 30 September 2015)

Drainage samples were collected on seven occasions in the first year following installation of the fluxmeters. Total drainage volume was 611 mm (Figure 27b).

Nitrate-N and ammonium-N concentrations in drainage for this period averaged 33.7 mg/L and 1.0 mg/L respectively (Figure 27b). Nitrate-N concentrations peaked at 80.1 mg/L in mid-February 2015 before decreasing steadily over the autumn to spring period while ammonium-N concentrations remained low for the duration of Year 1 (< 1.2 mg/L). Measured mineral N losses from the system totalled 226 kg N/ha (Figure 27c) with the majority of N lost as nitrate-N (223 kg N/ha). Increased mineral N losses between May and September 2015 reflected the combination of elevated nitrate-N concentrations in drainage and high drainage volumes.

Total P and DRP concentrations averaged 0.14 mg/L and 0.12 mg/L respectively (Figure 28b). Measured P losses from the system were low, totalling 0.49 kg P/ha with DRP loss accounting for 0.45 kg P/ha (Figure 28c).

Year 2 (1 October 2015 to 30 September 2016)

Drainage samples were collected on ten occasions in the second year following installation of the fluxmeters. Total drainage volume was 411 mm (Figure 27b).

Nitrate-N and ammonium-N concentrations in drainage for this period averaged 27.6 mg/L and 0.02 mg/L respectively (Figure 27b). Measured mineral N losses from the system totalled 75 kg N/ha (Figure 27c) with N lost almost entirely as nitrate-N. While still relatively high, mineral N losses were considerably lower than those observed over the Year 1 monitoring period (226 kg N/ha). As in Year 1, drainage nitrate-N concentrations peaked in mid-February (70.1 mg/l) before decreasing over the winter through to spring period (June to September). High nitrate concentrations over the late summer and early autumn period were consistent with a number of site and management factors including 1) the location of the experimental site on a free draining soil type, 2) increased fertiliser N inputs over the late spring to early summer period and 3) the application of regular irrigation over the summer months which likely maintained soil moisture levels close to field capacity (Figure 26).

Total P and DRP concentrations over this period remained low and averaged 0.06 mg/L and 0.06 mg/L respectively (Figure 28b). Measured P losses from the system were minimal (0.20 kg P/ha; Figure 28c).

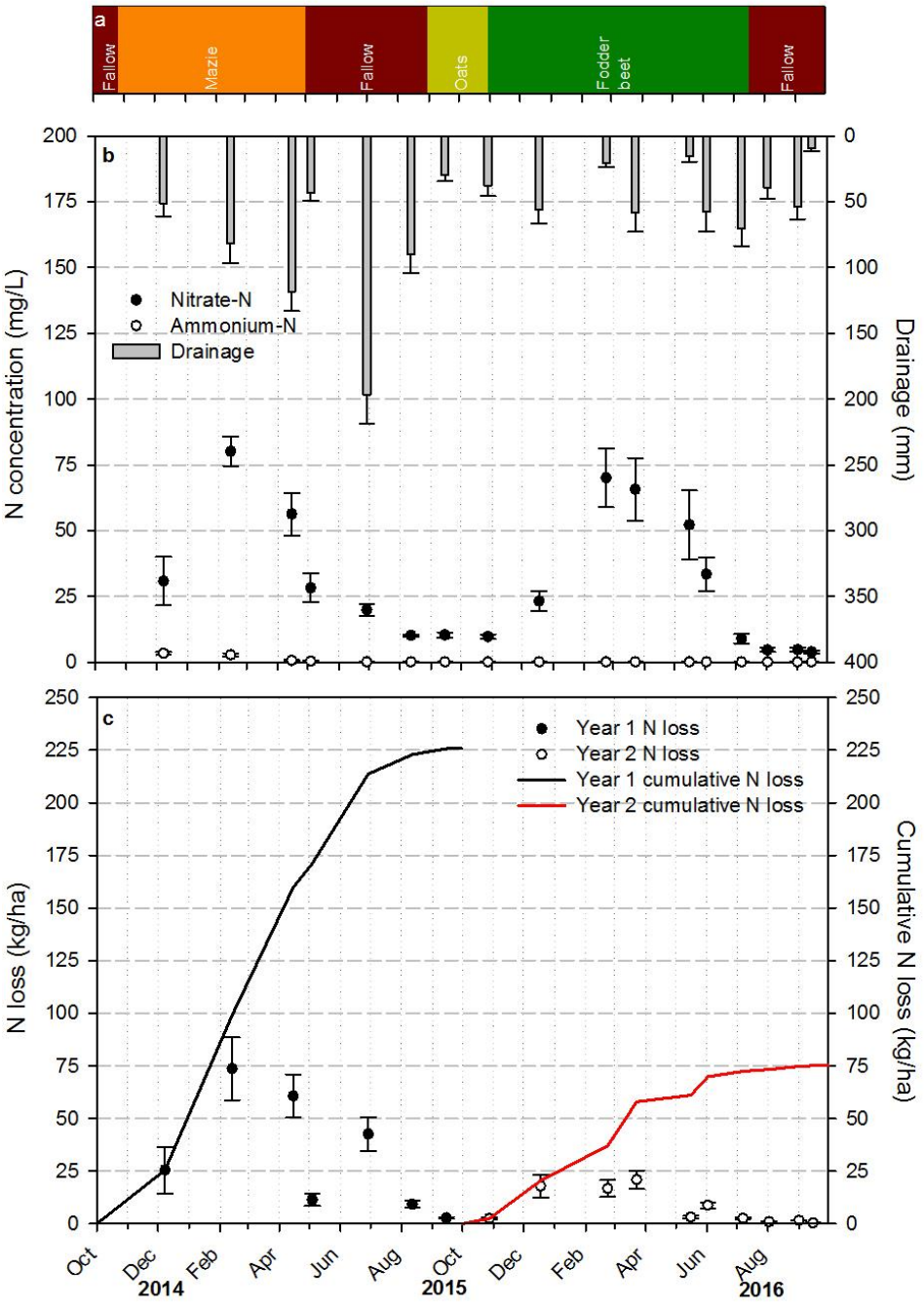

Figure 27. Summary of crop sequence (a), measured drainage and inorganic N concentrations (nitrate-N and ammonium-N) in drainage (b) and measured system losses of inorganic N in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) (c) Site 5 — Manawatu. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: nitrate-N: 0.02 mg/L; ammonium-N: 0.01 mg/L. Fluxmeters were installed on 29 September 2014.

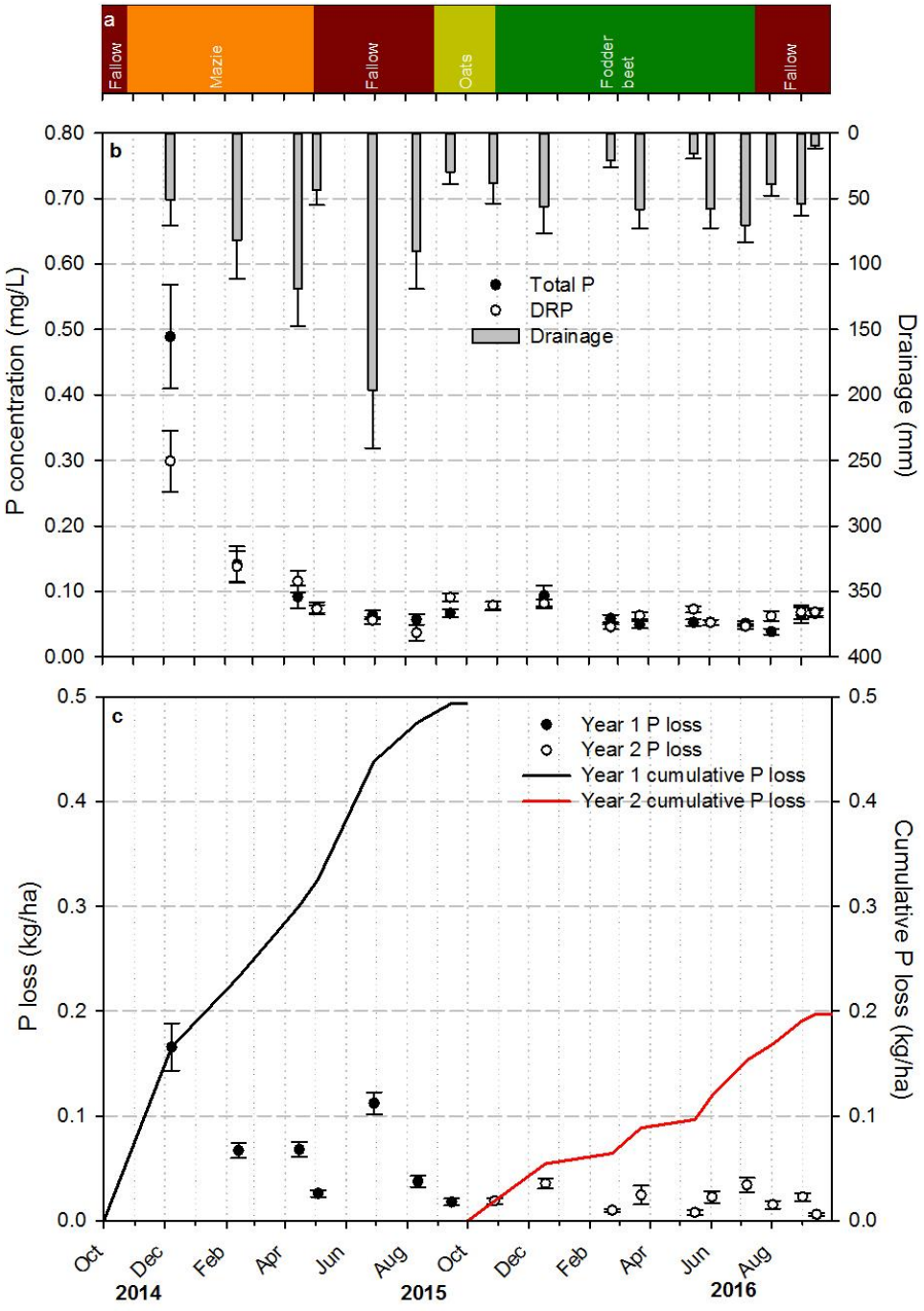

Figure 28. Summary of crop sequence (a), measured drainage and P concentrations (total P and DRP) in drainage (b) and measured system losses of total P in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) (c) Site 5 — Manawatu. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: Total P: 0.02 mg/L; DRP: 0.001 mg/L. Fluxmeters were installed on 29 September 2014.

3.6 Site 6 — Manawatu

3.6.1 Background site and crop management history

Site 6 is located near Ohakune on a mixed cropping enterprise. Soil type is an Ohakune brown loam. Fluxmeters were installed at the site in April 2015. Key site characteristics are described in Table 12.

Table 12. Summary of key farm and site characteristics, Site 6 — Manawatu.

Location	Ohakune
Farming system	Mixed cropping
Topography	Flat
Soil type	Ohakune brown loam
Key soil characteristics[1]	Soil order: Typic orthic allophanic Texture: Silt loam Topsoil bulk density: 0.85 g/cm^3 Subsoil bulk density: 0.90 g/cm^3 Drainage class: Information not yet available N leaching vulnerability: Information not yet available
Previous land use history	Converted from pasture to mixed cropping in 2008.
Fluxmeter installation date	20 April 2015
Irrigation infrastructure	Travelling irrigator

[1]No description of the Ohakune brown loam is available online.

Since installation of the units there have been two crops of winter wheat. The first wheat crop was sown in May 2015 and harvested in February 2016. The site remained fallow until June 2016 when the current winter wheat crop was sown. Respective N and P inputs have totalled 69 kg N/ha and 0 kg P/ha (2015 wheat) and 0 kg N/ha and 20 kg P/ha (2016 wheat) (Table 13).

Table 13. Summary of crop management practices since fluxmeter installation (20 April 2015), Site 6 — Manawatu.

Crop management practices	Sequence 1 – Winter wheat	Sequence 2 – Winter wheat
Variety	'Wakanui'	'Wakanui'
Planting population	120 kg seed/ha	120 kg seed/ha
Planting date	6 May 2015	10 June 2016
Harvest date[1]	25 February 2016	Current crop
Cultivation practices	Disc followed by power harrow	Disc followed by power harrow
Fertiliser practices (product)[2]	150 kg N/ha Urea (S)	300 kg/ha MOP (P) 220 kg/ha Super10 (P)
Summed N and P (elemental)	N = 69 kg/ha P = 0 kg/ha	N = 0 kg/ha P = 20 kg/ha
Stock type	No stock	No stock
Stock density	-	-
Additional stock information	-	-

[1]Commercial harvest date. [2]B = base application, P = planting application, S= side dressing application(s).

3.6.2 General weather conditions

Year 1 (1 October 2014 to 30 September 2015)

Rainfall for the Year 1 period was 1401 mm, 8% above the long-term average for the region (1300 mm) (Figure 29a). The mid-autumn to early winter period (1 April to 30 June 2015) was particularly wet with close to two times the rainfall (572 mm) compared to the long-term average for the same period (304 mm).

Mean air temperature for the 12 month period was 10.1°C, cooler than the long-term average (11.0°C) (Figure 29b) while solar radiation totalled 4970 MJ/m^2, slightly less than the long-term average of 5330 MJ/m^2 (Figure 29c).

Year 2 (1 October 2015 to 30 September 2016)

Rainfall and mean air temperature for the Year 2 period was 1222 mm and 11.0°C, comparable to respective long-term averages for the region (Figure 29a and b). Most rainfall occurred between May and September 2016 (768 mm). Solar radiation for this period totalled 4912 MJ/m^2, lower than the long-term average (Figure 29c).

3.1.1 Soil nitrogen and phosphorus fertility levels

Soil samples for N and P fertility analyses were taken during installation of the fluxmeters in April 2015 and prior to sowing of the current wheat crop in June 2016.

Mineral N (0–100 cm)

Samples taken in April 2015 and June 2016 had high concentrations of mineral N (284 and 167 kg N/ha respectively) with the majority of this N present in the nitrate-N form (85–94%) (Figure 30a).

AMN (0–100 cm)

AMN concentrations were moderate (133 kg N/ha) and high (287 kg N/ha) for respective April 2015 and June 2016, within or above the normal concentrations suggested for wheat production (100–150 kg N/ha; Figure 30a).

Olsen P (0–20 cm)

Olsen P concentrations were moderate (24–26 mg/L, 0–20 cm depth) for both sampling occasions and within the normal concentrations suggested for wheat production (20–30 mg/L) (Figure 30b).

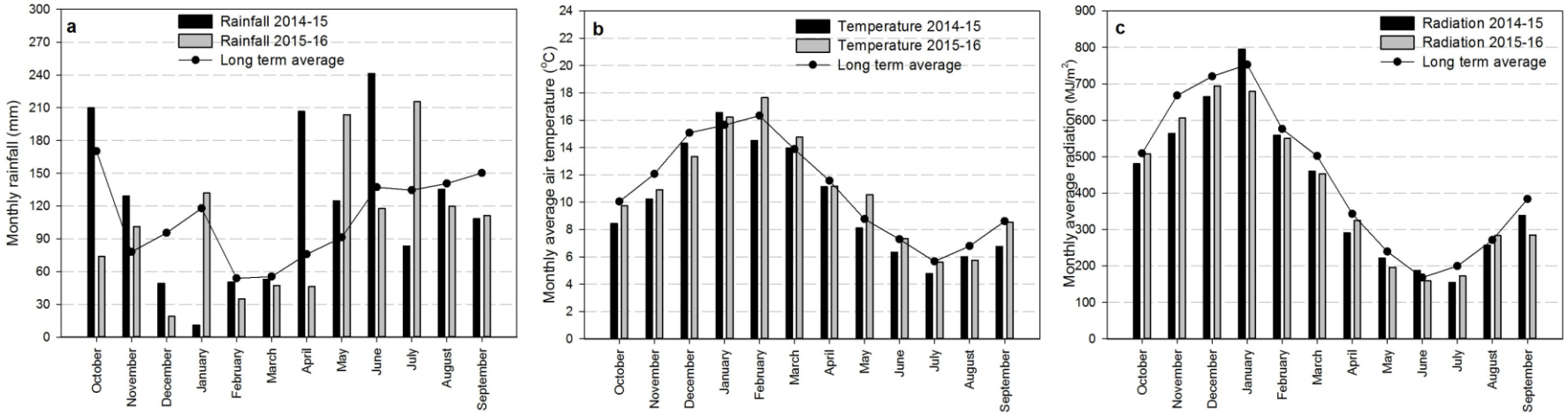

Figure 29. Monthly (a) rainfall (mm), (b) average air temperature (°C) and average solar radiation (MJ/m^2) for 1 October 2014 to 30 September 2016 at Ohakune (rainfall and temperature: NIWA Station 31624) and Mount Ruapehu (radiation; NIWA Station 18464). Long-term climate data (2008–14) presented are for the Ohakune station.

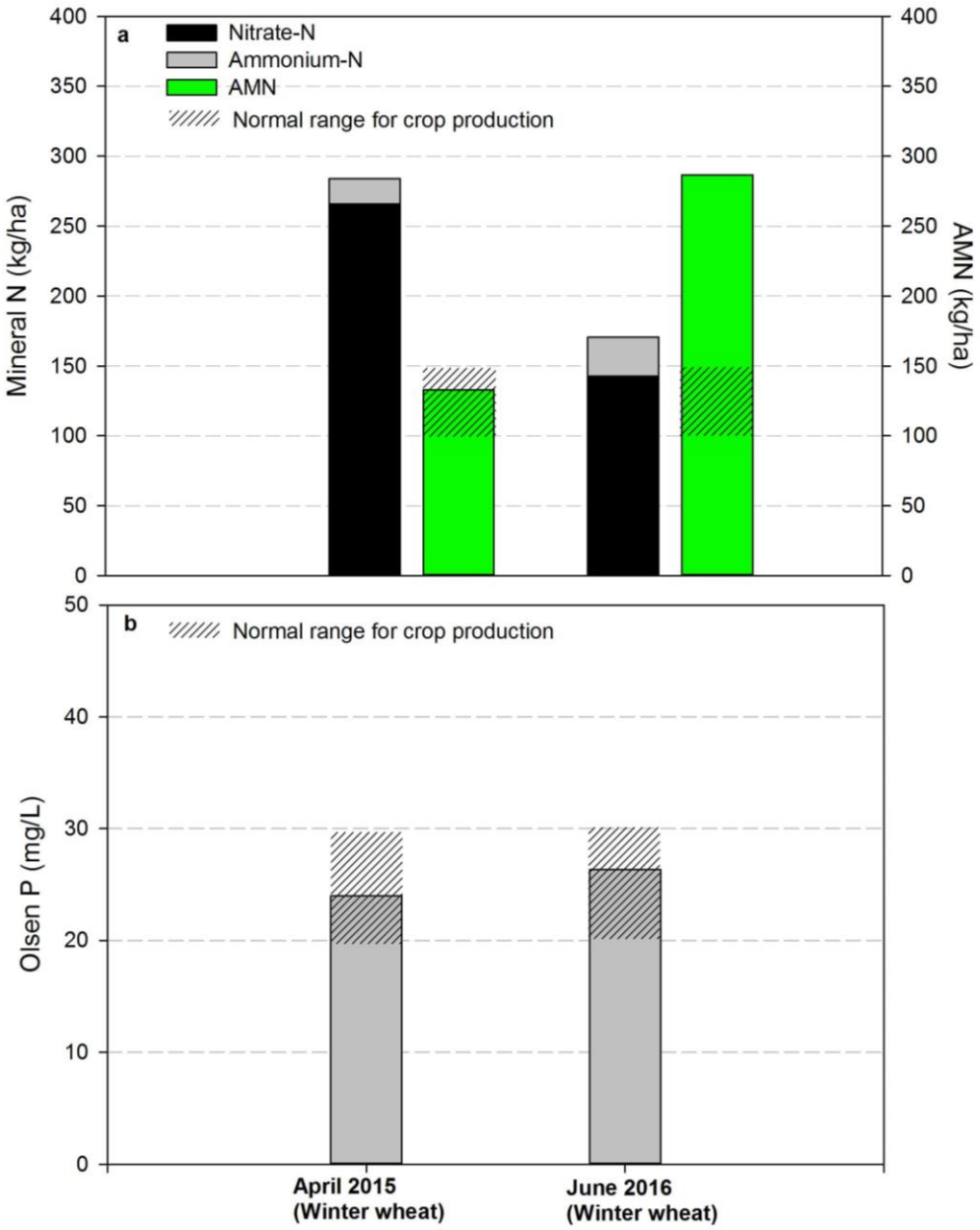

Figure 30. Soil mineral N and AMN (0–100 cm depth) (a) and Olsen P (0–20 cm depth) (b) at Site 6 — Manawatu for samples taken in April 2015 and June 2016. Normal ranges suggested for crop production are provided by Hill Laboratories (http://www.hill-laboratories.com/page/pageid/2145845703/Crop_Guides).

3.6.3 Soil water balance

Year 1 (1 October 2014 to 30 September 2015)

The soil water balance for Site 6 is shown in Figure 31. Rainfall and irrigation for the Year 1 period totalled 1401 mm and 0 mm respectively. There was frequent and often heavy rainfall over the mid-autumn through to early spring period (April 2015 to September 2015) and consequently modelled soil water contents for all depths remained high over this period (> 110 mm). There were a number of significant rainfall events including 138 mm over 7 days in early April 2015 and 100 mm over 2 days in mid-June 2015. Drainage collection commenced in July 2015.

Year 2 (1 October 2015 to 30 September 2016)

Rainfall and irrigation for the Year 2 period totalled 1222 mm and 0 mm respectively. Rainfall occurred at regular intervals over the monitoring period, however the late autumn and winter period (May to August 2016) was especially wet with prolonged periods of rainfall including 103 mm over 7 days in late May, 85 mm over 8 days in late June and 141 mm over 9 days in late August (Figure 31).

Modelled soil water contents followed a similar trend to Year 1, decreasing over the summer period and early autumn period (in response to less rainfall and crop water use) before increasing to high levels (> 110 mm) over the winter to early spring period. There were six drainage collections, three between early November 2015 and late February 2016 and three between mid-June and mid-September 2016.

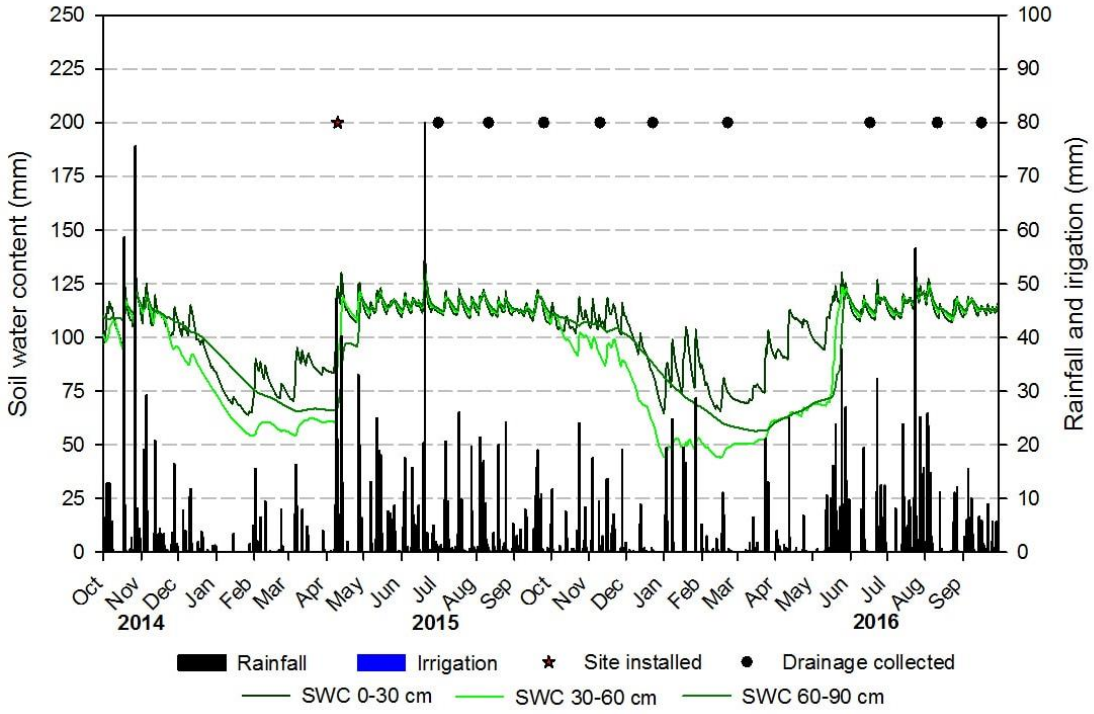

Figure 31. Summary of daily rainfall, irrigation and modelled soil water content (0–30 cm, 30–60 cm and 60–90 cm) from 1 October 2014, Site 6 — Manawatu.

3.6.4 Losses of N and P in drainage water

Year 1 (1 October 2014 to 30 September 2015)

Drainage samples were collected on three occasions in the first year following installation of the fluxmeters. Total drainage volume was 196 mm (Figure 32b).

Nitrate-N and ammonium-N concentrations in drainage for this period averaged 17.5 mg/L and 0.7 mg/L respectively (Figure 32b). Nitrate-N concentrations increased from 12 mg/L in July to around 20 mg/L in August and September. Ammonium-N concentrations remained low for the duration of winter drainage period (< 0.8 mg/L). Measured mineral N losses from the system totalled 38 kg N/ha (Figure 32c) with the majority of N lost as nitrate-N (37 kg N/ha).

Total P and DRP concentrations averaged 0.11 mg/L and 0.09 mg/L respectively (Figure 33b). Measured P losses from the system were low, totalling 0.21 kg P/ha with DRP loss accounting for 0.19 kg P/ha (Figure 33c).

Year 2 (1 October 2015 to 30 September 2016)

Drainage samples were collected on six occasions in the second year following installation of the fluxmeters. Total drainage volume was 228 mm (Figure 32b).

Nitrate-N and ammonium-N concentrations in drainage for this period averaged 8.3 mg/L and 0.3 mg/L respectively (Figure 32b). Measured mineral N losses from the system totalled 16 kg N/ha (Figure 32c) and were lower than those observed in Year 1 (38 kg N/ha), reflecting lower nitrate-N concentrations in drainage over the Year 2 monitoring period. Nitrogen was lost almost entirely as nitrate-N.

Total P and DRP concentrations over this period remained low, averaging 0.03 mg/L and 0.03 mg/L respectively (Figure 33b). Measured P losses from the system were minimal (0.06 kg P/ha; Figure 33c).

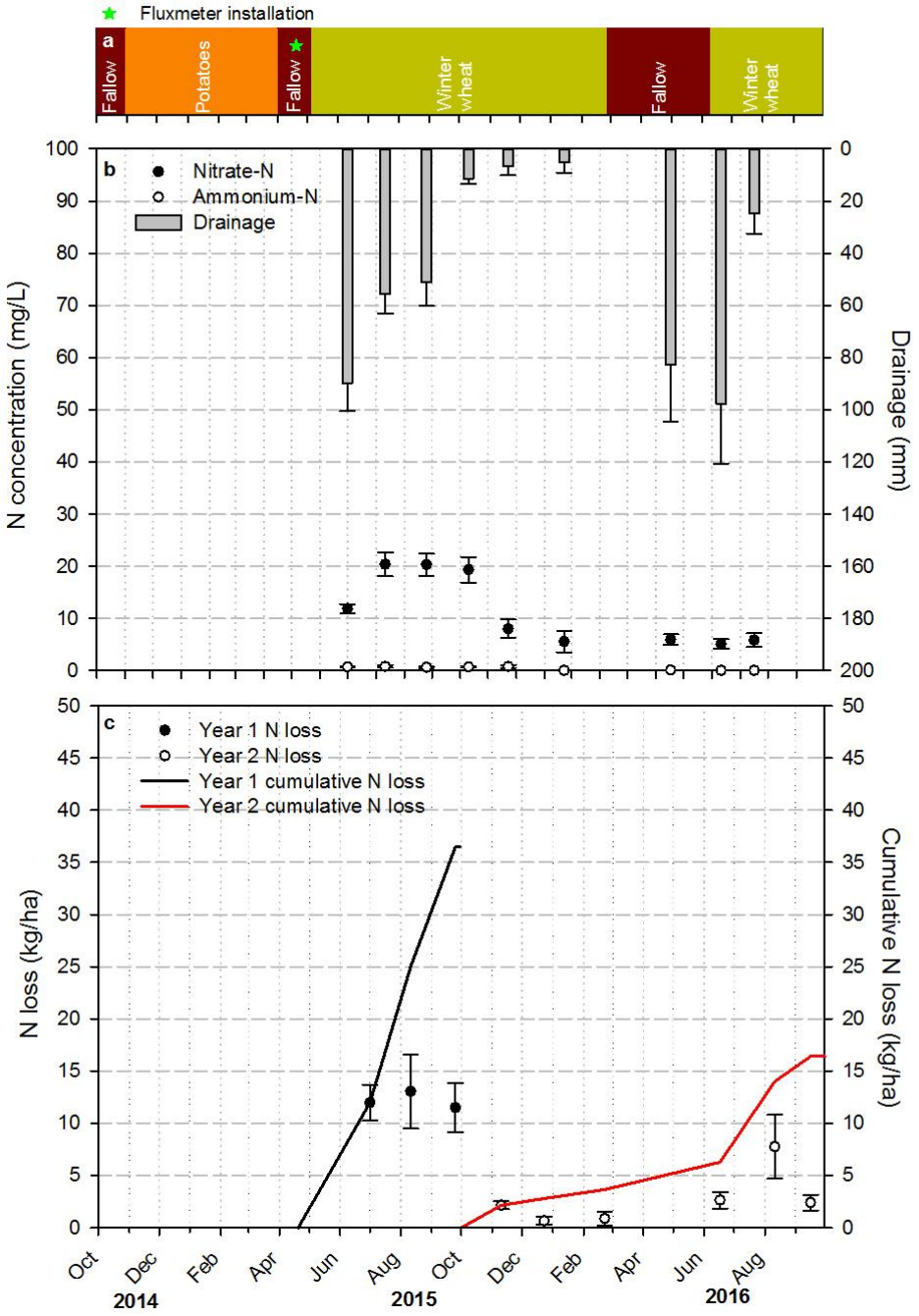

Figure 32. Summary of crop sequence (a), measured drainage and inorganic N concentrations (nitrate-N and ammonium-N) in drainage (b) and measured system losses of inorganic N in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) (c) Site 6 — Manawatu. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: nitrate-N: 0.02 mg/L; ammonium-N: 0.01 mg/L.

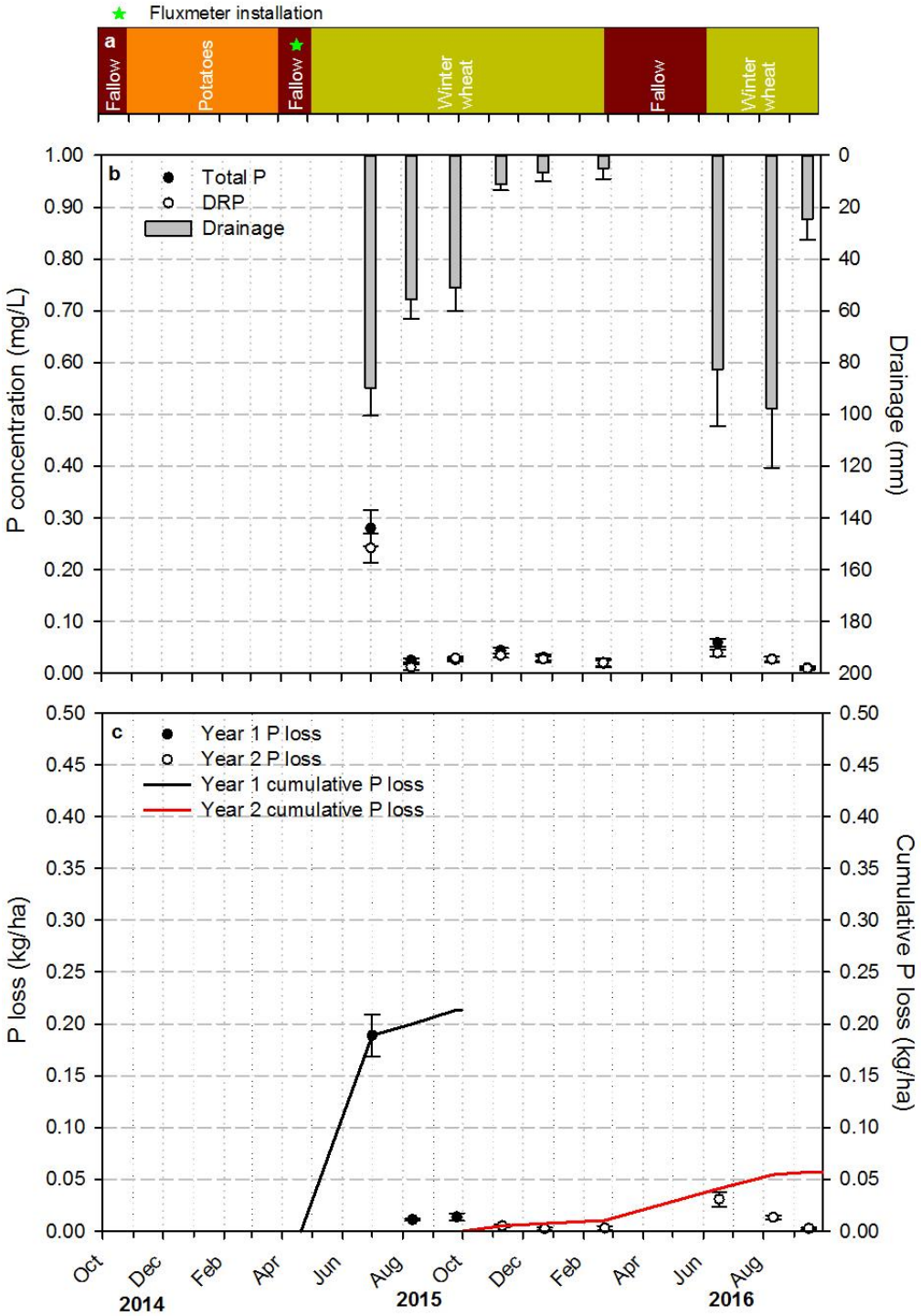

Figure 33. Summary of crop sequence (a), measured drainage and P concentrations (total P and DRP) in drainage (b) and measured system losses of total P in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) (c) Site 6 — Manawatu. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: Total P: 0.02 mg/L; DRP: 0.001 mg/L.

3.7 Site 7 — Hawke's Bay

3.7.1 Background site and crop management history

Site 7 is located near Otane on a mixed cropping and livestock grazing enterprise. Soil type is a Waimakariri silt loam. Fluxmeters were installed at the site in September 2014. Key site characteristics are described in Table 14.

Table 14. Summary of key farm and site characteristics, Site 7 — Hawke's Bay.

Location	Otane
Farming system	Mixed cropping, livestock grazing
Topography	Flat
Soil type	Waimakariri silt loam
Key soil characteristics[1]	Soil order: Weathered fluvial recent Texture: Silt loam over sandy loam Topsoil bulk density: 1.09 g/cm^3 Subsoil bulk density: 1.30 g/cm^3 Drainage class: Well drained N leaching vulnerability: Low
Previous land use history	Intensive cropping for past 10 years
Fluxmeter installation date	8 September 2014
Irrigation infrastructure	Centre pivot

[1]A full description of the Waimakariri silt loam is available online at https://smap.landcareresearch.co.nz/home. Listed characteristics are taken from S-MAP factsheets and are not based on measured site values.

Since installation of the units there have been four crops including carrots, two Italian ryegrass crops and peas (Table 15). Carrots were sown in September 2014 and harvested in January 2015. The site was then planted with Italian ryegrass in February 2015 for autumn and winter grazing before being direct drilled with peas in October 2015. The pea crop was harvested in January 2016 and the site subsequently planted with Italian ryegrass for autumn and winter grazing. The site is due to be planted to peas in mid-October. Respective N and P inputs have totalled 40 kg N/ha and 40 kg P/ha (carrots), 55 kg N/ha and 0 kg P/ha (ryegrass 2015), 0 kg N/ha and 32 kg P/ha (peas) and 169 kg N/ha and 0 kg P/ha (ryegrass 2016) (Table 15).

Table 15. Summary of crop management practices since fluxmeter installation (8 September 2014), Site 7 — Hawke's Bay.

Crop management practices	Sequence 1 — Carrots	Sequence 2 — Italian ryegrass	Sequence 3 — Peas	Sequence 4 — Italian ryegrass
Variety	'Nando'	'Moata'	'Ashton'	'Moata'
Planting population	5 kg/ha	28 kg/ha	214 kg seed/ha	25 kg/ha
Planting date	26 September 2014	28 February 2015	25 October 2015	22 January 2016
Harvest date[1]	22 January 2015	15 September 2015[2]	8 January 2016	20 September 2016[2]
Cultivation practices	Deep ripping followed by rotary hoe and bed formation	Levelled followed by speed disking	Disked and rolled followed by direct drill	Levelled followed by speed disking
Fertiliser practices (product)[3]	250 kg/ha Yaramila 16 (P)	120 kg/ha Urea (S)[4]	350 kg/ha Super ten with 15% boron (B)	367 kg/ha Urea (S)[5]
Summed N and P (elemental)	N = 40 kg/ha P = 40 kg/ha	N = 55 kg/ha P = 0 kg/ha	N = 0 kg/ha P = 32 kg/ha	N = 169 kg/ha P = 0 kg/ha
Stock type	No stock	Grazing lambs	No stock	Grazing lambs
Stock density	-	20 sheep/ha	-	20 sheep/ha
Additional stock information	-	Mid-April to September	-	Mid-April to September

[1]Commercial harvest date. [2]Reflects the date the ryegrass was sprayed off. [3]B = base application, P = planting application, S= side dressing application(s). [4]Applied as a single application in early April. [5]Applied in early April (217 kg/ha) and mid-August (150 kg/ha)

3.7.2 General weather conditions

Year 1 (1 October 2014 to 30 September 2015)

Rainfall and mean air temperature for the Year 1 period was 661 mm, 14% below than the long-term average for the region (765 mm) (Figure 34a). Rainfall for the winter to early spring period (June to September 2015) was 309 mm, comparable with the long-term average for this period (333 mm).

Average air temperature for the 12 month period was12.2°C, cooler than the long-term average for the region (12.6°C) (Figure 34b) while solar radiation totalled 5658 MJ/m^2, slightly higher than the long-term average of 5366 MJ/m^2 (Figure 34c).

Year 2 (1 October 2015 to 30 September 2016)

Rainfall for the Year 2 period was 573 mm, 25% below the long-term average for the region. The period between February and July was particularly dry with 56% less rainfall recorded compared to the long-term average (444 mm).

Average air temperature for the 12 month period was 13.8°C, warmer than the long-term average while solar radiation totalled 5368 MJ/m^2, comparable to the long-term average for the region.

3.7.3 Soil nitrogen and phosphorus fertility levels

Soil samples for N and P fertility analyses were taken during installation of the fluxmeters in September 2014 and prior to establishment of crops in February 2015 (ryegrass), September 2015 (peas), February 2016 (ryegrass) and September 2016 (peas).

Mineral N (0–100 cm)

Samples taken in September 2014, February 2015 and February 2016 had moderate concentrations of mineral N (101–129 kg N/ha) with the majority of N present as nitrate-N (80–82%). In contrast mineral N concentrations were low for samples taken in September 2015 and September 2016 (35–41 kg N/ha) with the a greater proportion of this N present as ammonium-N (51–72%) (Figure 35a).

AMN (0–100 cm)

AMN concentrations were generally low for all sampling occasions (57–101 kg N/ha) and below normal concentrations suggested for carrot and ryegrass production (100–150 kg N/ha; Figure 35a).

Olsen P (0–20 cm)

Olsen P concentrations were moderate for all sampling occasions (26–31 mg/L). Concentrations were slightly below normal concentrations suggested for carrot (35–75 mg/L) and pea (30–55 mg/L) production but within normal concentrations suggested for ryegrass production (20–30 mg/L) (Figure 35b).

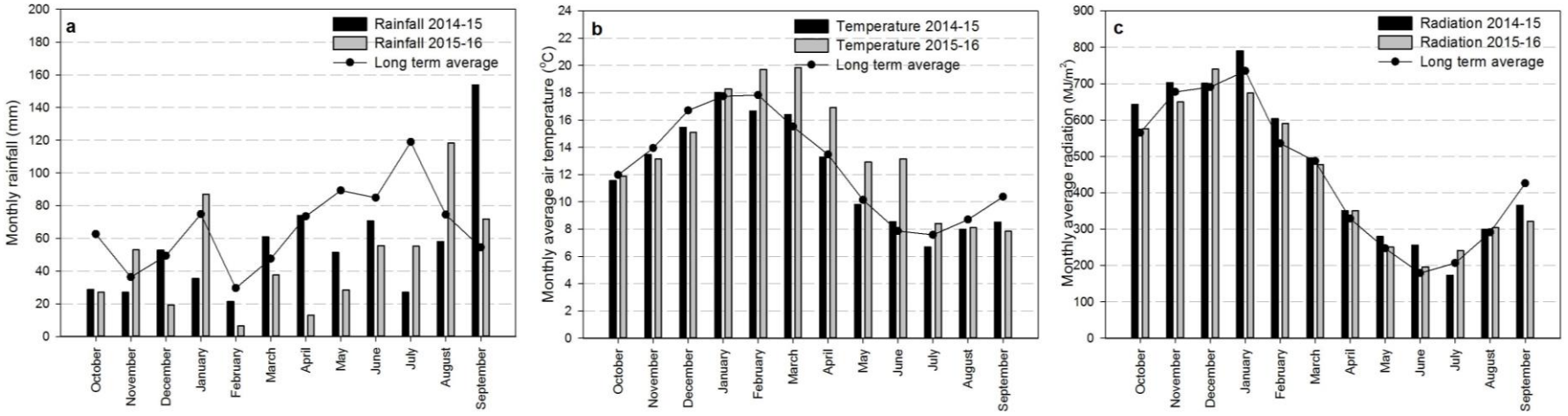

Figure 34. Monthly (a) rainfall (mm), (b) average air temperature (°C) and average solar radiation (MJ/m^2) for 1 October 2014 to 30 September 2016 at Te Aute (rainfall: Hawke's Bay Regional Council Station) and Waipawa (temperature and radiation; NIWA Station 31620). Long-term climate data (2008–14) are presented for the Waipawa station.

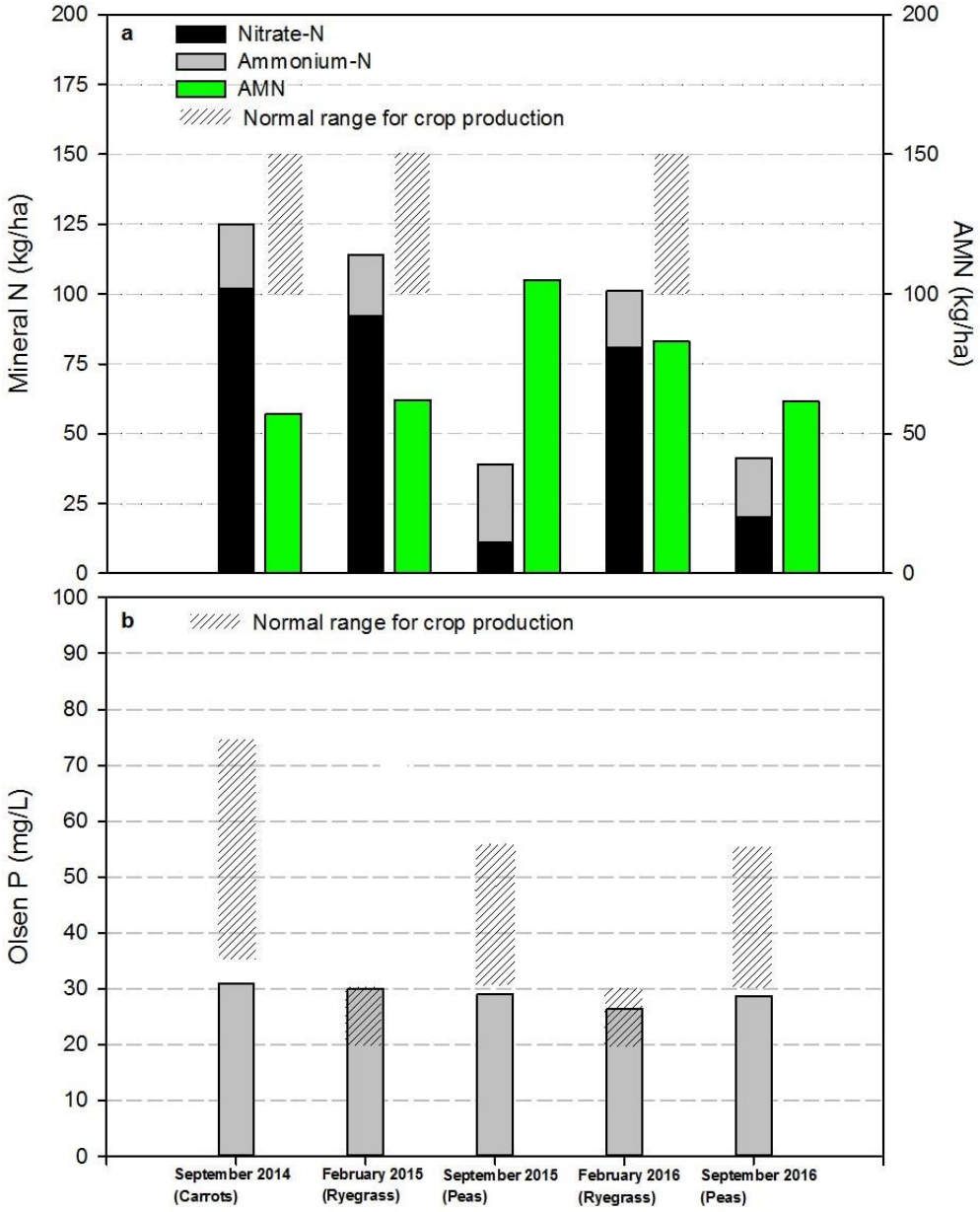

Figure 35. Soil mineral N and AMN (0–100 cm depth) (a) and Olsen P (0–20 cm depth) (b) at Site 7 — Hawke's Bay for samples taken in September 2014, February 2015, September 2015, February 2016 and September 2016. Normal ranges suggested for crop production are provided by Hill Laboratories (http://www.hill-laboratories.com/page/pageid/2145845703/Crop_Guides).

3.7.4 Soil water balance

Year 1 (1 October 2014 to 30 September 2015)

The soil water balance for Site 7 is shown in Figure 36. Rainfall and irrigation for the Year 1 period totalled 661 mm and 88 mm respectively. There were two rainfall events over 50 mm, one in early April 2015 (53 mm over 4 days) and one in late September (119 mm over 5 days). The range in individual irrigation application volumes was 3 to 20 mm.

Modelled soil water contents tended to decrease over the summer and early autumn period before increasing over the autumn through to early spring period. In general, drainage samples were collected when modelled soil moisture contents increased above 100 mm (Figure 36).

Year 2 (1 October 2015 to 30 September 2016)

Rainfall and irrigation for the Year 2 period totalled 573 mm and 140 mm respectively. The largest rainfall event occurred in early August when 80 mm was recorded over 4 days (Figure 36). Irrigation was applied between late November and early April with application volumes ranging from 10 to 20 mm.

Modelled soil water contents tended to decrease from early December onwards in response to less rainfall and an increase in crop water use. However, in contrast to Year 1, soil water contents remained at low levels through the autumn and early winter period (March to June) before increasing to high levels (> 100 mm) over the late winter and early spring period (August to September). There were five drainage collections, two between early November 2015 and late February 2016 and three between mid-June and mid-September 2016.

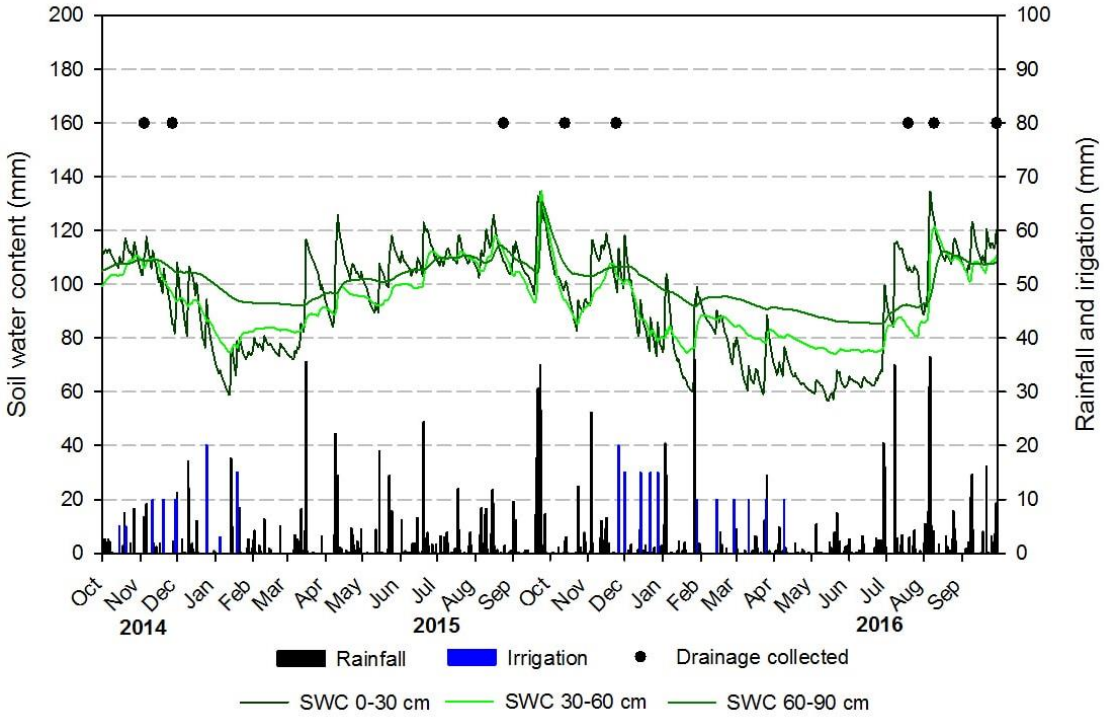

Figure 36. Summary of daily rainfall, irrigation and modelled soil water content (0–30 cm, 30–60 cm and 60–90 cm) from 10 October 2014, Site 7 – Hawke's Bay. Fluxmeters were installed on 8 September 2014.

3.7.5 Losses of N and P in drainage water

Year 1 (1 October 2014 to 30 September 2015)

Drainage samples were collected on three occasions following installation of the fluxmeters. Total drainage volume was 20 mm (Figure 37b).

Nitrate-N and ammonium-N concentrations in drainage for this period averaged 4.2 mg/L and 1.1 mg/L respectively (Figure 37b). Due to low drainage volumes measured mineral N losses from the system was low totalling 1.7 kg N/ha (Figure 37c), with the majority of this N lost as nitrate-N (1.3 kg N/ha).

Total P and DRP concentrations averaged 0.22 mg/L and 0.14 mg/L respectively (Figure 38b). Measured P losses from the system were minimal (< 0.01 kg P/ha; Figure 38c).

Year 2 (1 October 2015 to 30 September 2016)

Drainage samples were collected on five occasions in the second year following installation of the fluxmeters. Total drainage volume of 21 mm (Figure 37b).

Nitrate-N and ammonium-N concentrations in drainage for this period averaged 12.3 mg/L and 0.2 mg/L respectively (Figure 37b) while respective total P and DRP concentrations averaged 0.38 mg/L and 0.37 mg/L respectively. As in Year 1, low drainage volumes meant that mineral N and total P losses were low (1.7 kg N/ha and 0.06 kg P/ha; Figures 37c and 38c respectively).

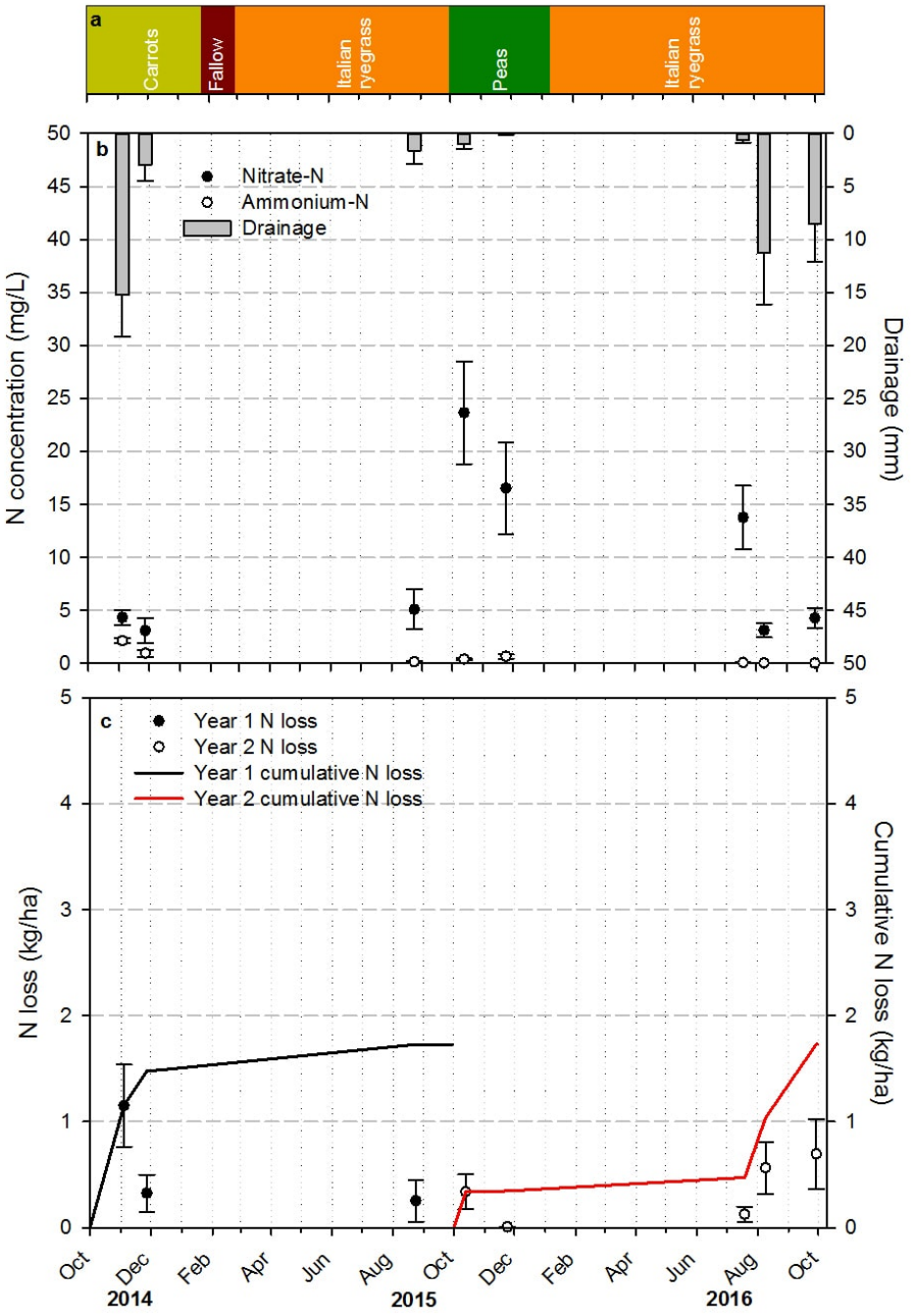

Figure 37. Summary of crop sequence (a), measured drainage and inorganic N concentrations (nitrate-N and ammonium-N) in drainage (b) and measured system losses of inorganic N in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) (c) Site 7 — Hawke's Bay. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: nitrate-N: 0.02 mg/L; ammonium-N: 0.01 mg/L. Fluxmeters were installed on 8 September 2014.

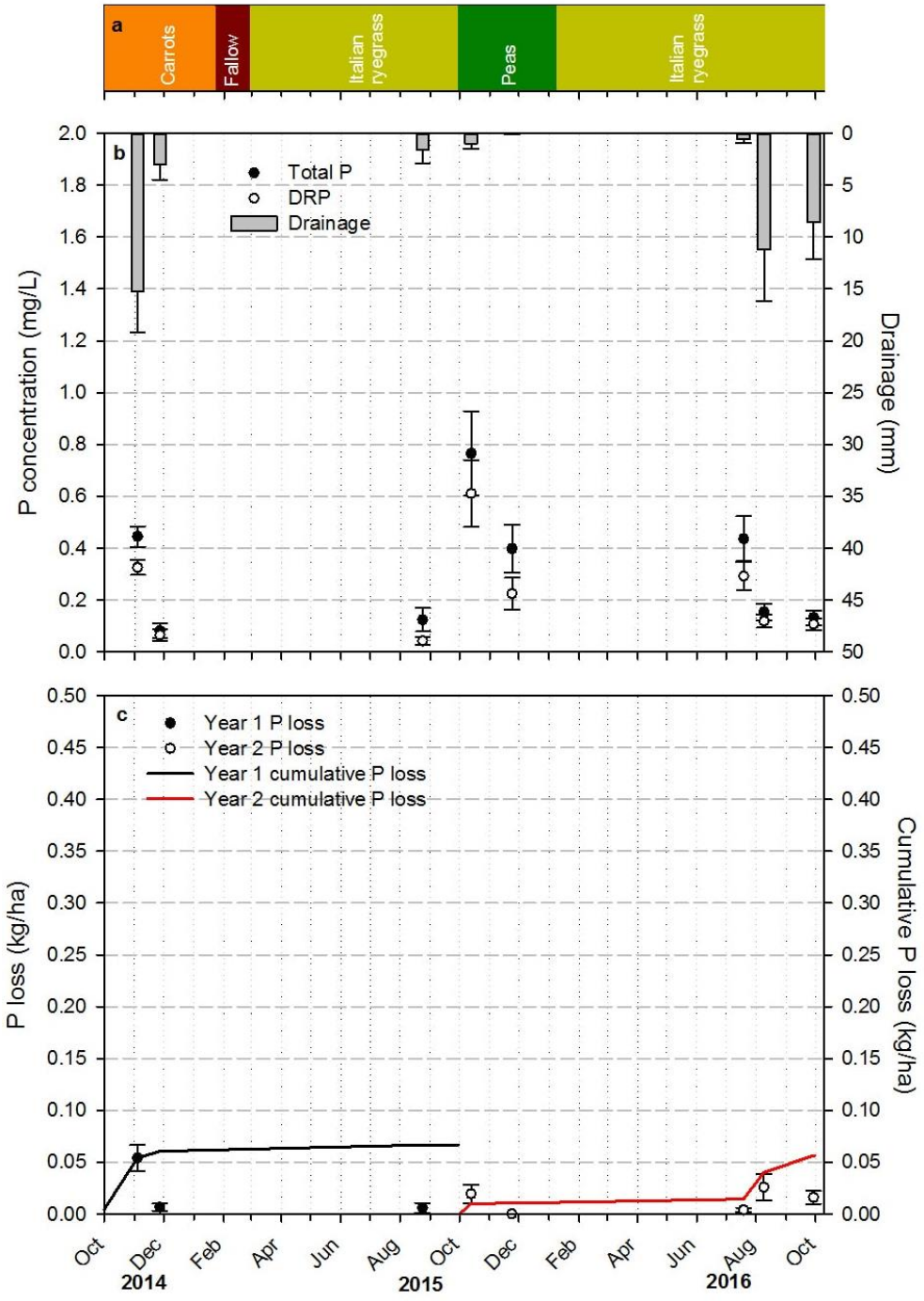

Figure 38. Summary of crop sequence (a), measured drainage and P concentrations (total P and DRP) in drainage (b) and measured system losses of total P in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) (c) Site 7 — Hawke's Bay. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: Total P: 0.02 mg/L; DRP: 0.001 mg/L. Fluxmeters were installed on 8 September 2014.

3.8 Site 8 – Hawke's Bay

3.8.1 Background site and crop management history

Site 8 is located near Hastings on a mixed cropping and livestock grazing enterprise. Soil type is a Waimakariri silt loam. Fluxmeters were installed at the site in October 2014. Key site characteristics are described in Table 16.

Table 16. Summary of key farm and site characteristics, Site 8 — Hawke's Bay.

Location	Hastings
Farming system	Mixed cropping, livestock grazing
Topography	Flat
Soil type	Waimakariri silt loam
Key soil characteristics[1]	Soil order: Weathered fluvial recent Texture: Silt loam over sandy loam Topsoil bulk density: 1.09 g/cm^3 Subsoil bulk density: 1.30 g/cm^3 Drainage class: Well drained N leaching vulnerability: Low
Previous land use history	Mixed cropping since 2002 (under orchard prior to 2002)
Fluxmeter installation date	2 October 2014
Irrigation infrastructure	Gun

[1]A full description of the Waimakariri silt loam is available online at https://smap.landcareresearch.co.nz/home. Listed characteristics are taken from S-MAP factsheets and are not based on measured site values.

Since installation of the fluxmeters there have been three crops including sweetcorn, Italian ryegrass and processing tomatoes (Table 17). Sweetcorn was sown in December 2014 and harvested in March 2015. The site was then planted with Italian ryegrass in March 2015 for autumn and winter grazing before being planted with process tomatoes in October 2015. The tomato crop was harvested in March 2016 and the site subsequently sown to Italian ryegrass for autumn and winter grazing. The site is due to be planted to sweetcorn in mid-October. Respective N and P inputs for the sweetcorn, ryegrass (2015), process tomatoes and ryegrass (2016) crops have totalled 308 kg N/ha and 41 kg P/ha (sweetcorn), 0 kg N/ha and 0 kg P/ha (ryegrass 2015), 271 kg N/ha and 85 kg P/ha (process tomatoes) and 0 kg N/ha and 0 kg P/ha (ryegrass 2016) (Table 17).

Table 17. Summary of crop management practices since fluxmeter installation (2 October 2014), Site 8 — Hawke's Bay.

Crop management practices	Sequence 1 — Sweetcorn	Sequence 2 — Italian ryegrass	Sequence 3 — Process tomatoes	Sequence 4 — Italian ryegrass
Variety	'Punch'	'Tabu'	'H3402'	'Moata'
Planting population	67,000 seeds/ha	30 kg/ha	25,000 plants/ha	30 kg/ha
Planting date	8 December 2014	28 March 2015	27 October 2015	19 March 2016
Harvest date[1]	20 March 2015	30 September 2015[2]	5 March 2016	21 September 2016[2]
Cultivation practices	Disc followed by power harrow	Disc	Plough followed by power harrow and bed formation	Deep rip followed by disc and cultipress
Fertiliser practices (product)[3]	250 kg/ha Cropzeal20 (B)[4] 300 kg/ha Urea (B)[4] 175 kg/ha Cropzeal 16 (P) 200 kg/ha Urea (P)	None applied	300 kg/ha DAP (P) 400 kg/ha SOP (P) 100 kg/ha Yara Mila Faster (P) 200 kg/ha CAN (S) 350 kg/ha Mila complex (S) 125 kg/ha Nitrabor (S) 175 kg/ha KNO_3 (S)	None applied
Summed N and P (elemental)	N = 308 kg/ha P = 41 kg/ha	N = 0 kg/ha P = 0 kg/ha	N = 219 kg/ha P = 85 kg/ha	N = 0 kg/ha P = 0 kg/ha
Stock type	No stock	Sheep	No stock	Sheep
Stock density	-	25 lambs/ha	-	25 lambs/ha
Additional stock information	-	May to September 2015	-	May to September 2016

[1]Commercial harvest date. [2]Reflects the date the ryegrass was sprayed off. [3]B = base application, P = planting application, S= side dressing application(s). [4]Applied at initial planting on 29 October 2014; crop was later re-sown on 8 December 2014 because of poor emergence.

3.8.2 General weather conditions

Year 1 (1 October 2014 to 30 September 2015)

Rainfall for the Year 1 period was 651 mm, 8% below the long-term average for the region (711 mm) (Figure 39a). Rainfall for the winter to early spring period (1 June to 30 September) was 294 mm, comparable with the long-term average (277 mm).

Average air temperature was 12.6°C, cooler than the long-term average (13.3°C) (Figure 39b) while solar radiation totalled 5844 MJ/m^2 was higher than the long-term average of 5391 MJ/m^2 (Figure 39c).

Year 2 (1 October 2015 to 30 September 2016)

Rainfall for the Year 2 period was 596 mm, 16% below the long-term average for the region. The period between February and July was particularly dry with half the amount of rainfall recorded (204 mm) compared to the long-term average (409 mm).

Average air temperature for the 12 month period was 13.8°C, warmer than the long-term average while solar radiation totalled 5485 MJ/m^2 was comparable to the long-term average for the region.

3.8.3 Soil nitrogen and phosphorus fertility levels

Soil samples for N and P fertility analyses were taken during installation of the fluxmeters in September 2014, April 2015, October 2015, April 2016 and October 2016 prior to establishment of the respective sweetcorn (2015), ryegrass (2015), tomato, ryegrass (2016) and sweetcorn (2016) crops.

Mineral N (0–100 cm)

Mineral N concentrations were moderate for samples taken in September 2014 (126 kg N/ha) and low for samples taken in September 2015 (29 kg N/ha) and September 2016 (34 kg N/ha). In contrast concentrations were high for samples taken at the end of the summer cropping sequences in April 2015 and 2016 (233–363 kg N/ha). Nitrate N was the predominant form of mineral N for all sampling occasions (70–95%).

AMN (0–100 cm)

AMN concentrations remained fairly consistent across the four sampling occasions (88 to 119 kg N/ha), slightly below normal concentrations suggested for sweetcorn and tomato production (100–150 kg N/ha) (Figure 40a).

Olsen P (0–20 cm)

Olsen P concentrations were moderate for all sampling occasions (34 to 40 mg/L). Concentrations were slightly above the normal concentrations suggested for maize (15–30 mg/L) and ryegrass (20–30 mg/L), but below those suggested for tomatoes (70–150 mg/L) (Figure 40b).

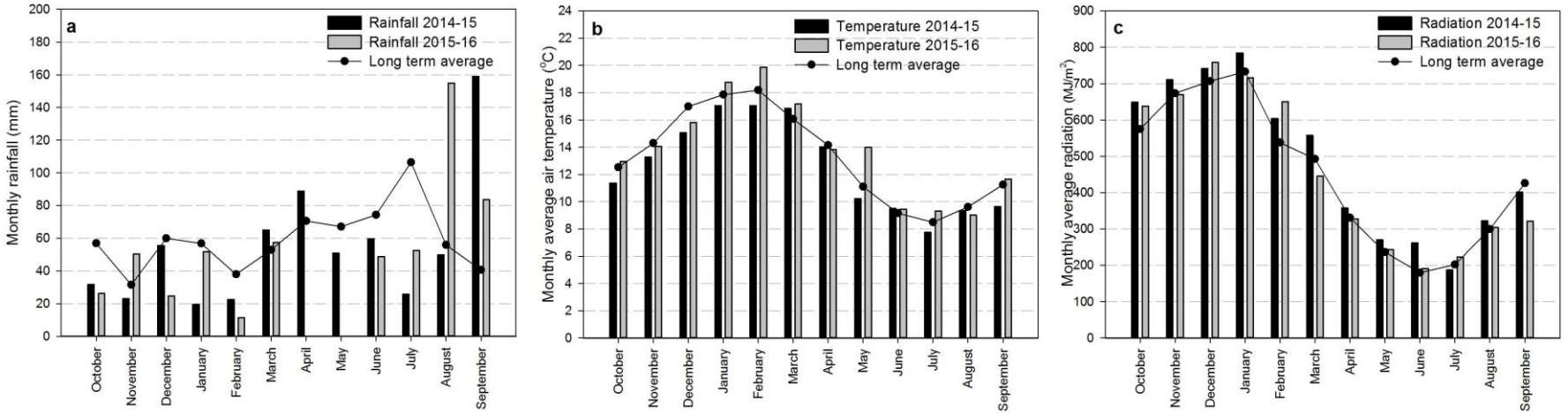

Figure 39. Monthly (a) rainfall (mm), (b) average air temperature (°C) and average solar radiation (MJ/m^2) for 1 October 2014 to 30 September 2016 at Longlands (rainfall; Hort Plus station) and Whakatu (temperature and radiation; NIWA Station 15876). Long-term rainfall (2004–14) and long-term temperature and radiation (2001–14) data are presented for the Longlands and Whakatu stations respectively.

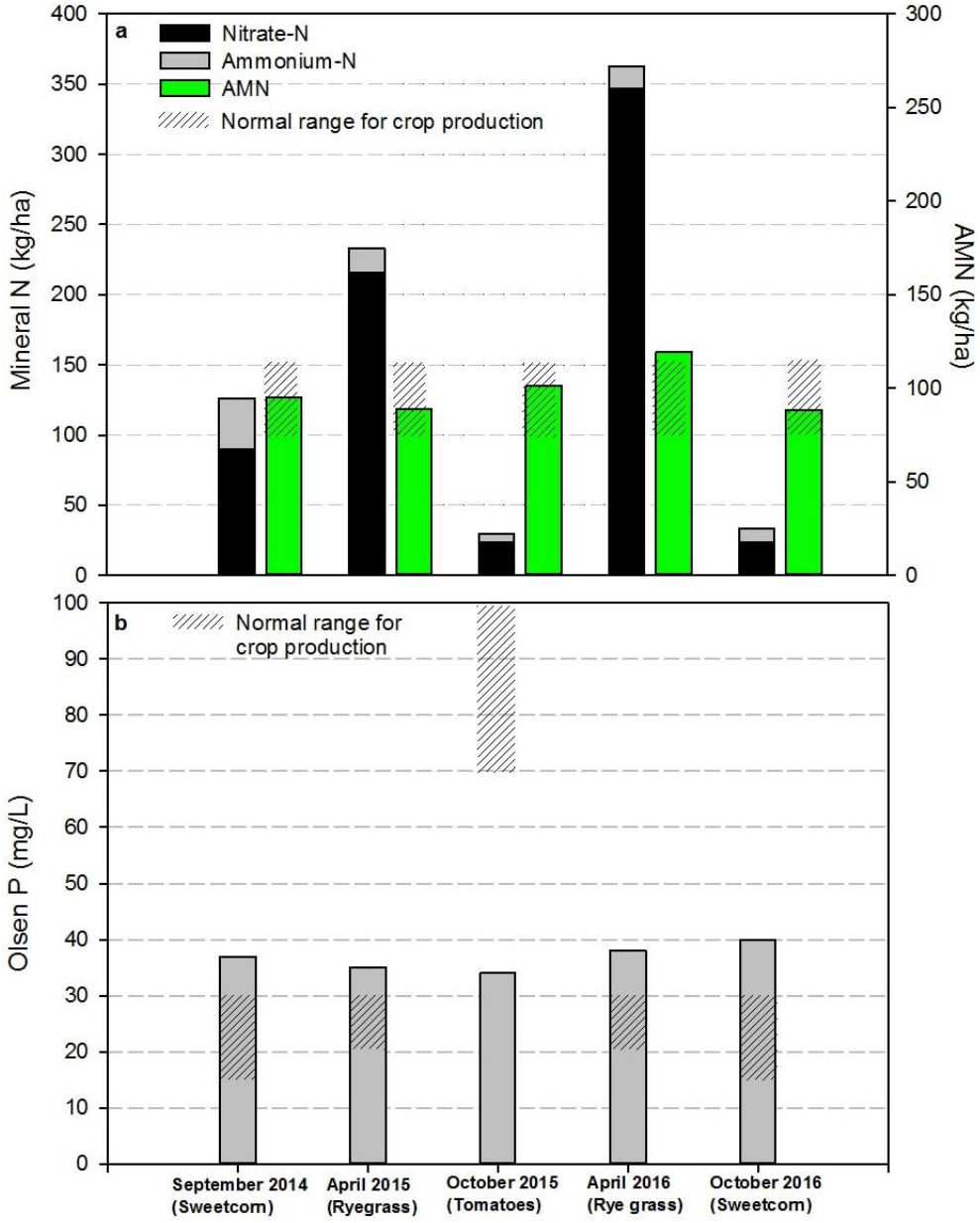

Figure 40. Soil mineral N and AMN (0–100 cm depth) (a) and Olsen P (0–20 cm depth) (b) at Site 8 — Hawke's Bay for samples taken in September 2014, April 2015 and October 2015. Normal ranges suggested for crop production are provided by Hill Laboratories (http://www.hill-laboratories.com/page/pageid/2145845703/Crop_Guides).

3.8.4 Soil water balance

Year 1 (1 October 2014 to 30 September 2015)

The soil water balance for Site 8 is shown in Figure 41. Rainfall and irrigation for the Year 1 period totalled 651 mm and 76 mm respectively. There were two rainfall events over 50 mm, one in early April 2015 (66 mm over 3 days) and one in late September (146 mm over 6 days). Irrigation was applied at 38 mm per application.

Modelled soil water contents at the 60–90 cm depth remained low for the duration of the monitoring period (< 80 mm) except for a period in late September 2015 when values increased following a significant rainfall event. One small drainage sample was collected after this event.

Year 2 (1 October 2015 to 30 September 2016)

Rainfall and irrigation for the Year 2 period totalled 596 mm and 150 mm respectively. The largest rainfall event occurred in early August when 116 mm was recorded over 3 days (Figure 41). Irrigation was applied five times between late December and mid-February at between 11 and 44 mm per application.

There was a progressive decrease in modelled soil water contents over the summer through to early winter period (December 2015 to June 2016). This trend was consistent with below average rainfall over this period, particularly over the autumn period (March to May) where rainfall was 53% below the long-term average for this period (Figure 39). There were no drainage samples collected during the monitoring period.

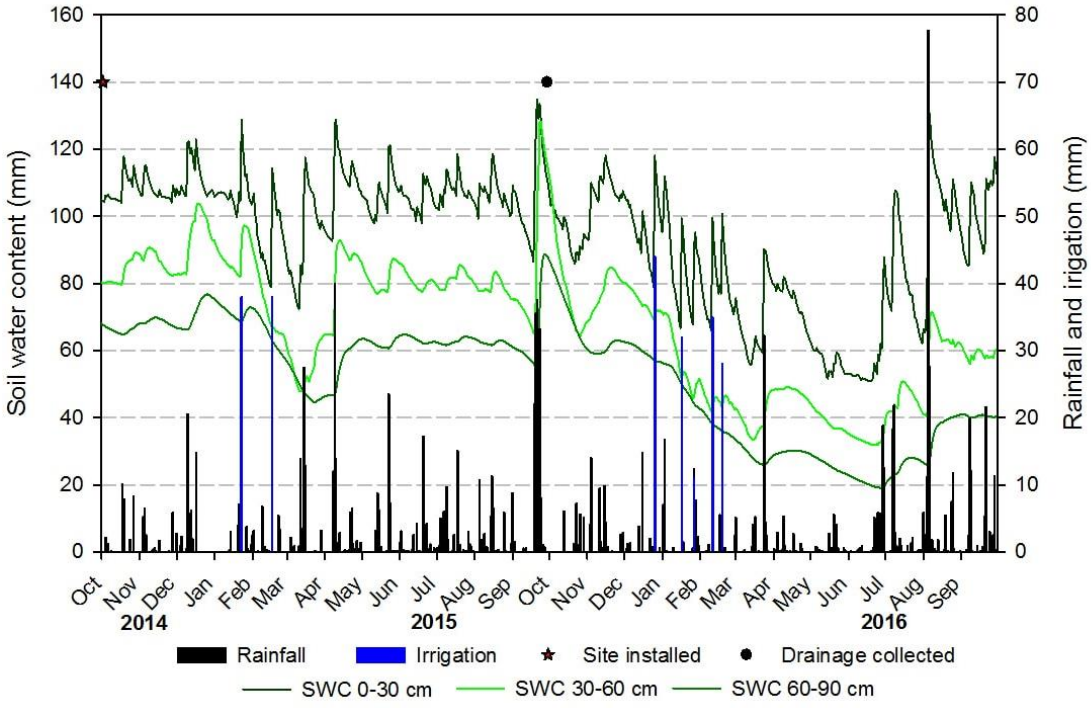

Figure 41. Summary of daily rainfall, irrigation and modelled soil water content (0–30 cm, 30–60 cm and 60–90 cm) from 1 October 2014, Site 8 — Hawke's Bay.

3.8.5 Losses of N and P in drainage water

Year 1 (1 October 2014 to 30 September 2015)

Captured drainage for Year 1 was 0.3 mm. There was only one drainage sampling in this period in late September 2015 (Figure 42b).

Nitrate-N and ammonium-N concentrations in drainage averaged 21.5 mg/L and 3.1 mg/L respectively (Figure 42b) while respective total P and DRP concentrations averaged 0.38 mg/L and 0.23 mg/L (Figure 43b). Due to low drainage volumes, measured mineral N and total P losses were minimal (< 0.5 kg N/ha and < 0.1 kg P/ha; Figures 42c and 43c respectively)

Year 2 (1 October 2015 to 30 September 2016)

There were no drainage samples collected in the second year following installation of the fluxmeters (Figure 42b) and consequently there are no losses of N and P to report.

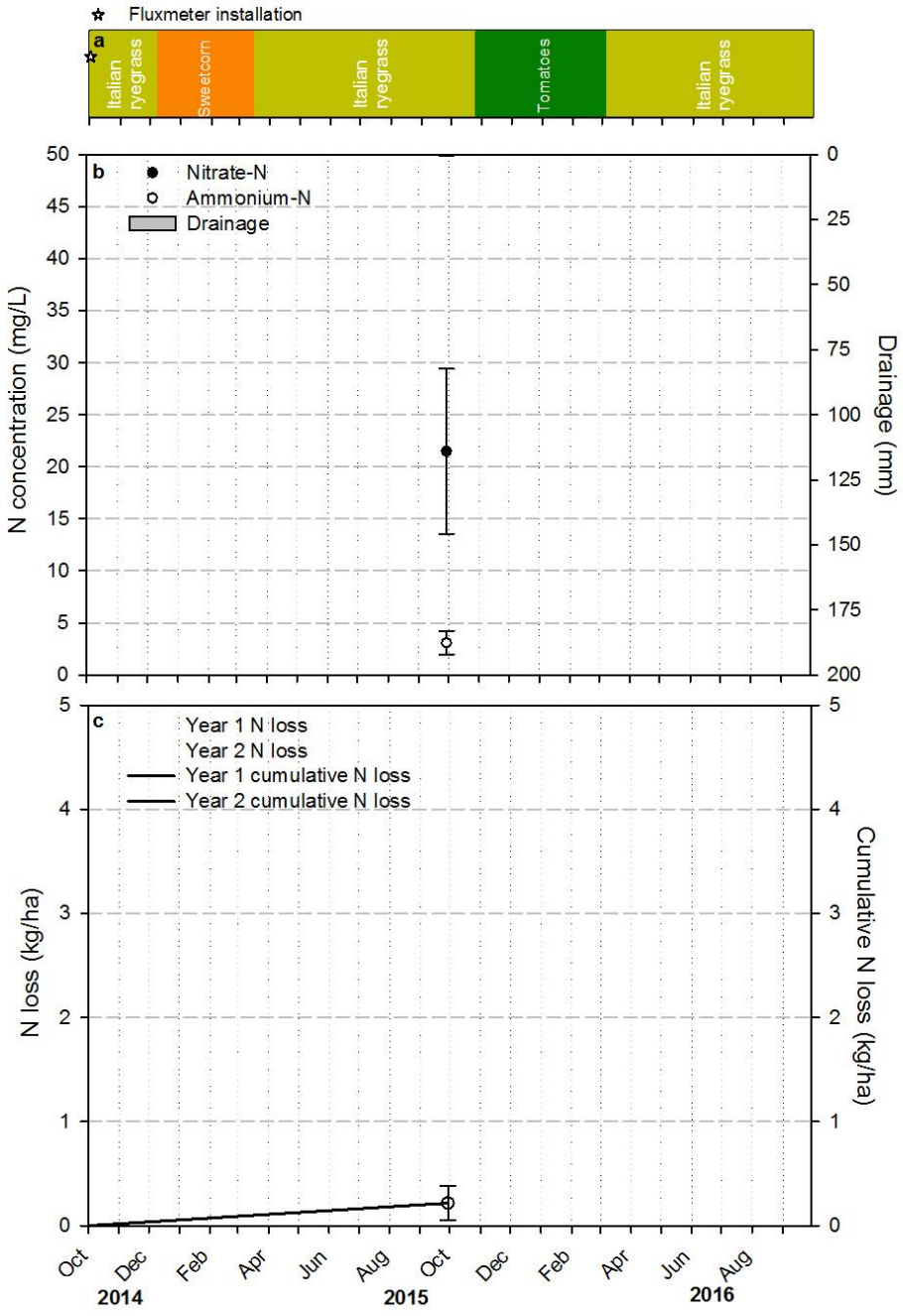

Figure 42. Summary of crop sequence (a), measured drainage and inorganic N concentrations (nitrate-N and ammonium-N) in drainage (b) and measured system losses of inorganic N in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) (c) Site 8 — Hawke's Bay. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: nitrate-N: 0.02 mg/L; ammonium-N: 0.01 mg/L.

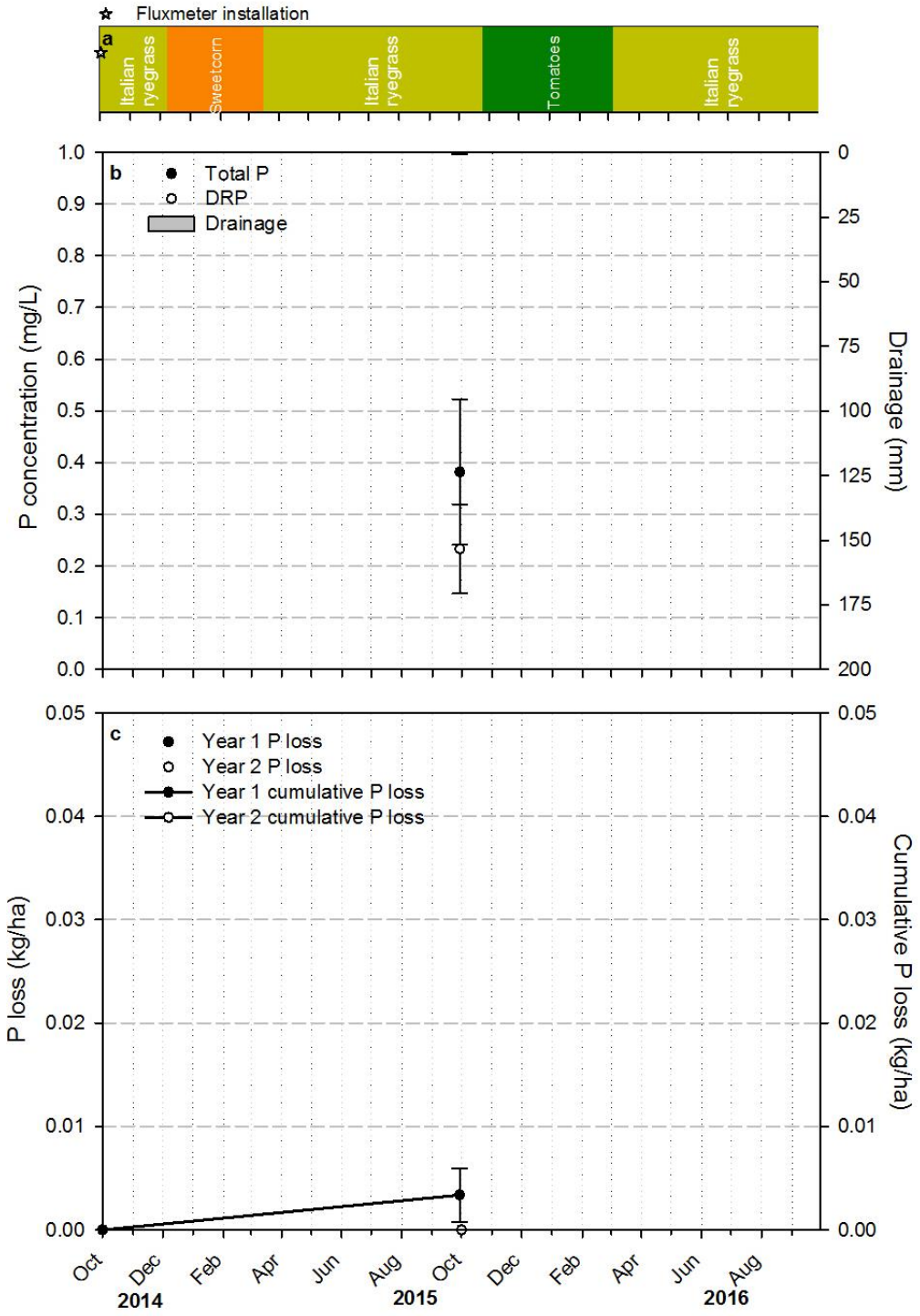

Figure 43. Summary of crop sequence (a), measured drainage and P concentrations (total P and DRP) in drainage (b) and measured system losses of total P in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) (c) Site 8 — Hawke's Bay. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: Total P: 0.02 mg/L; DRP: 0.001 mg/L.

3.9 Site 9 – Hawke's Bay

3.9.1 Background site and crop management history

Site 9 is located near Takapau on a mixed cropping and livestock grazing enterprise. Soil type is a Takapau silt loam. Fluxmeters were installed at the site in September 2014. Key site characteristics are described in Table 18.

Table 18. Summary of key farm and site characteristics, Site 9 — Hawke's Bay.

Location	Takapau
Farming system	Mixed cropping, livestock grazing
Topography	Flat
Soil type	Takapau silt loam
Key soil characteristics[1]	Soil order: Typic allophanic brown Texture: Silty loam Topsoil bulk density: 1.09 g/cm^3 Subsoil bulk density: 1.42 g/cm^3 Drainage class: Well drained N leaching vulnerability: Medium
Previous land use history	Mixed cropping and pasture. Converted to permanent cropping 4 years ago.
Fluxmeter installation date	4 September 2014
Irrigation infrastructure	Centre pivot

[1]A full description of the Takapau silt loam is available online at https://smap.landcareresearch.co.nz/home. Listed characteristics are taken from S-MAP factsheets and are not based on measured site values.

Since installation of the fluxmeters there have been three crops including peas, beans, barley and Italian ryegrass (Table 19). Peas were sown in September 2014 and harvested in December 2014. The site was then planted with beans in (December 2014) which were subsequently grazed by 2-year-old bulls between late April and mid-May 2015 (the crop was bypassed by the processor). Following grazing the site remained fallow until August 2015 before being planted with barley. The barley crop was harvested in January 2016 and the site planted with Italian ryegrass in March 2016 for autumn and winter grazing. The Italian ryegrass will be harvested for seed in January 2017. Respective N and P inputs have totalled 0 kg N/ha and 0 kg P/ha (peas), 50 kg N/ha and 30 kg P/ha (beans), 113 kg N/ha and 23 kg P/ha (barley) and 46 kg N/ha and 0 kg P/ha (Italian ryegrass) (Table 19).

Table 19. Summary of crop management practices since fluxmeter installation (4 September 2014), Site 9 — Hawke's Bay.

Crop management practices	Sequence 1 — Peas	Sequence 2 — Beans	Sequence 3 — Barley	Sequence 4 — Italian ryegrass
Variety	'Ashton'	'Clarion'	'Jimpy'	'Moata'
Planting population	200 kg/ha	380,000 seeds/ha	130 kg seed/ha	15 kg seed/ha
Planting date	12 September 2014	30 December 2014	24 August 2015	4 March 2016
Harvest date[1]	26 December 2014	24 April 2015[2]	30 January 2016	Current crop
Cultivation practices	Deep rip (40 cm) followed by discing and power harrow	Ploughed and then rolled	Disced followed by powerharrow	Ploughed and then rolled
Fertiliser practices (product)[3]	None applied	200 kg/ha Potash gold (P) 125 CAN kg/ha (S)	2000 kg/ha Lime (B) 140 kg/ha Urea (B) 150 kg/ha Potash super (B) 80 kg/ha Cropmaster DAP (P) 75 kg/ha Urea (S)	400 kg/ha Urea (S)[4]
Summed N and P (elemental)	N = 0 kg/h P = 0 kg/ha	N = 50 kg/ha P = 30 kg/ha	N = 113 kg/ha P = 23 kg/ha	N = 184 kg/ha P = 0 kg/ha
Stock type	No stock	2-year old bulls	No stock	Sheep and beef
Stock density	-	4.2 cows/ha	-	6.5 to 10 lambs/ha 10 ewes/ha 1.3 yearlings and heifers/ha
Additional stock information	-	-	-	200 x 8 week lambs in July and August 300 lambs and 300 ewes from mid-September to early October 20 x 2 year old bulls and 20 x yearlings from September to October

[1]Commercial harvest date. [2]Crop was bypassed and subsequently grazed by cattle over a 4-week period between late-April and mid-May 2015. [3]B = base application, P = planting application, S= side dressing application(s). [4]Applied as 100 kg/ha in mid-April, 100 kg/ha in mid-September and 200 kg/ha in mid-November.

3.9.2 General weather conditions

Year 1 (1 October 2014 to 30 September 2015)

Rainfall for the Year 1 period was 1035 mm, 7% below the long-term average for the region (1112 mm) (Figure 44a). Rainfall for the winter and spring period (June to September 2015) was 655 mm, comparable with the long-term average for this period (627 mm).

Mean air temperature for the 12 month period was 11.3°C cooler than the long-term average (11.8 °C) (Figure 44b) while solar radiation totalled 4968 MJ/m^2, comparable with the long-term average of 5006 MJ/m^2 (Figure 44c).

Year 2 (1 October 2015 to 30 September 2016)

Rainfall and mean air temperature for the Year 2 period was 989 mm, 11% below the long-term average for the region (Figure 44a). Rainfall for the winter and spring period (June to November 2016) was 569 mm, slightly less than the long-term average for this period (627 mm).

Mean air temperature for the 12 month period was 12.1°C slightly warmer than the long-term average (Figure 44b) while solar radiation totalled 5319 MJ/m^2, moderately higher than the long-term average (Figure 44c).

3.9.3 Soil nitrogen and phosphorus fertility levels

Soil samples for N and P fertility analyses were taken during installation of the fluxmeters in September 2014 and prior to establishment of the respective bean, barley and Italian ryegrass crops in January 2015, August 2015 and January 2016.

Mineral N (0–60 cm)

Mineral N concentrations increased from low in September 2014 (32 kg N/ha) to moderate in January 2015 (71 kg N/ha) and then high in August 2015 (185 kg N/ha) (Figure 45a). Samples for the August soil sampling were taken a few weeks after a base application of urea fertiliser (Table 19). Increased mineral N concentrations for this sample reflect this N application in addition to previous management history which included grazing of the earlier legume crop by bulls and associated urinary N inputs (April to May 2015). Mineral N concentrations for samples taken in January 2016 were low (58 kg N/ha). Nitrate N was the predominant form of mineral N for all sampling occasions (63–100%).

AMN (0–60 cm)

AMN concentrations (0–60 cm depth) remained consistently high across the three sampling occasions (182 to 219 kg N/ha) and were above normal concentrations suggested for barley and Italian ryegrass (100–150 kg N/ha) (Figure 45a).

Olsen P (0–20 cm)

Olsen P concentrations were moderate for samples taken in September 2014, January 2015 and August 2015 (21 to 27 mg/L) and low for samples taken in January 2016 (17 mg/L) (Figure 45b). Concentrations were slightly below normal concentrations suggested for peas (30–55 mg/L), beans (35–75 mg/L) and ryegrass (20–30 mg/L), but within normal concentrations suggested for barley (20–30 mg/L).

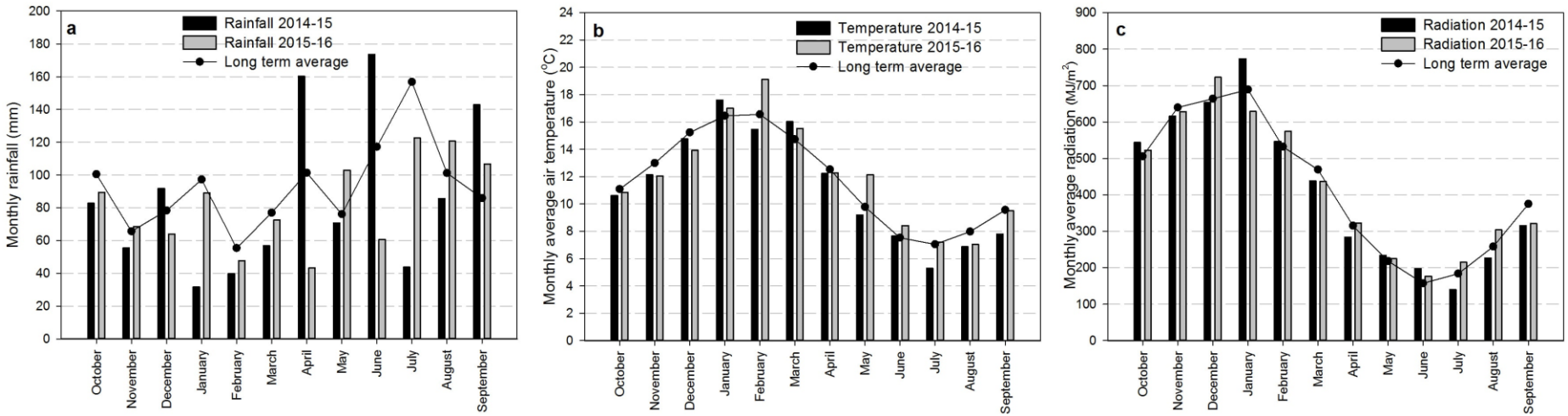

Figure 44. Monthly (a) rainfall (mm), (b) average air temperature (°C) and average solar radiation (MJ/m^2) for 1 October 2014 to 30 September 2016 at Takapau (rainfall and temperature; NIWA Station 25820) and Waipawa (radiation; NIWA Station 31620). Long-term climate data (2006–14) are presented for the Takapau and Waipawa stations.

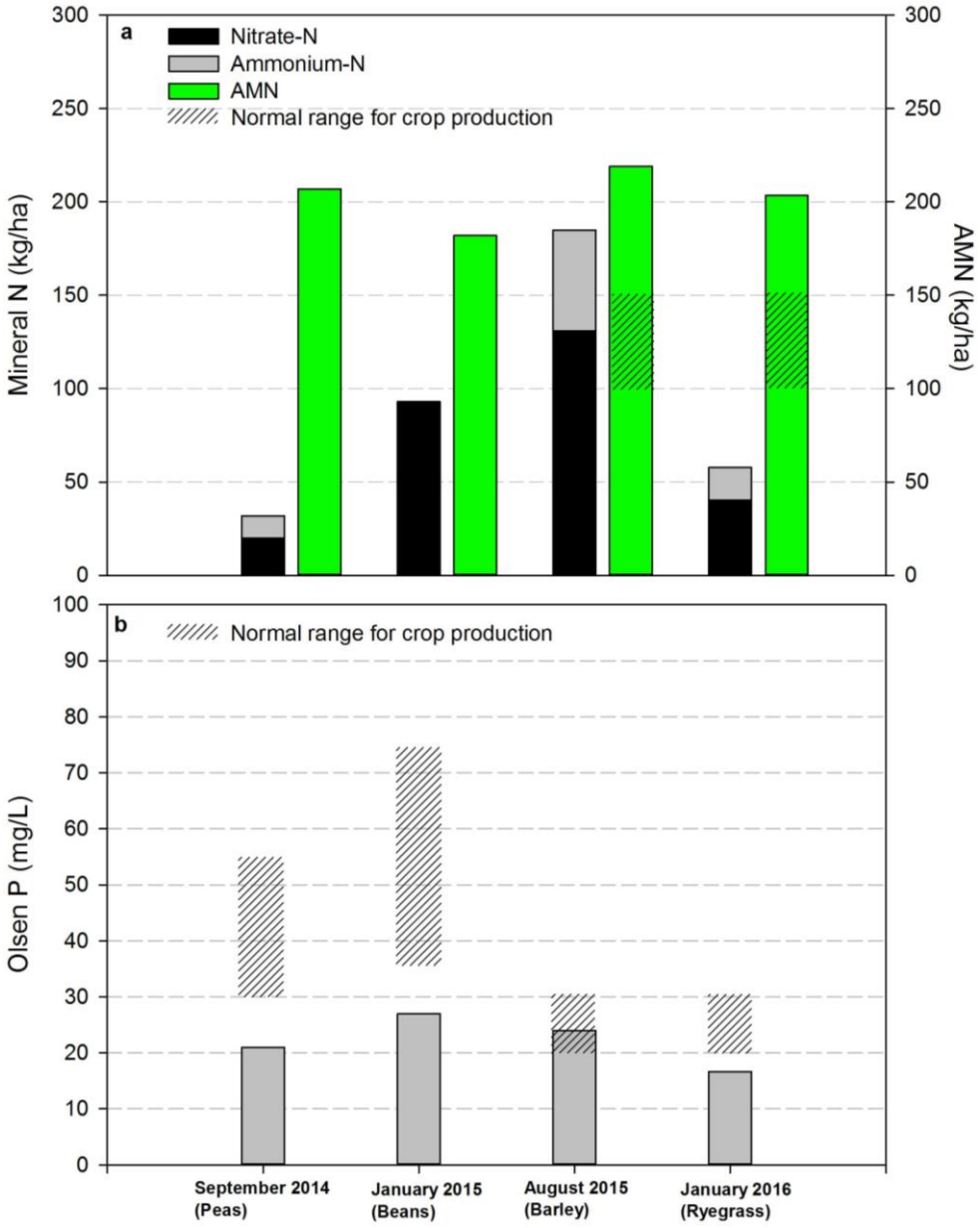

Figure 45. Soil mineral N and AMN (0–60 cm depth) (a) and Olsen P (0–20 cm depth) (b) at Site 9—— Hawke's Bay for samples taken in September 2014, January 2015, August 2015 and January 2016. Normal ranges suggested for crop production are provided by Hill Laboratories (http://www.hill-laboratories.com/page/pageid/2145845703/Crop_Guides).

3.9.4 Soil water balance

Year 1 (1 October 2014 to 30 September 2015)

The soil water balance for Site 9 is shown in Figure 46. Rainfall and irrigation for the Year 1 period totalled 1035 mm and 103 mm respectively. There were three rainfall events over 50 mm, one in early April 2015 (86 mm over 3 days), one in mid-June (71 mm over 3 days) and one in late September (116 mm over 6 days). The range in individual irrigation application volumes was 10 to 30 mm.

Modelled soil water contents increased to above 100 mm from mid-April 2015 and remained at elevated for the duration of the late autumn through to early spring period. The majority of drainage samples were collected during this period.

Year 2 (1 October 2015 to 30 September 2016)

Rainfall and irrigation for the Year 2 period totalled 989 mm and 150 mm respectively. The largest rainfall events occurred in early August when 61 mm was recorded over 4 days (Figure 46). There were seven irrigation applications between late November and early January (irrigation volumes ranged from 10 to 25 mm per application).

Modelled soil water contents remained at comparatively high levels for the 0–30 and 30–60 cm depths (> 80 mm) for the duration of the monitoring period. For the 60–90 cm depth, modelled soil water contents remained at lower levels over the summer to autumn period (December to May) before increasing in August in response to regular rainfall. Six drainage samples were collected over the Year 2 monitoring period including two between early October and late November 2015 and four between early July and mid-September 2016.

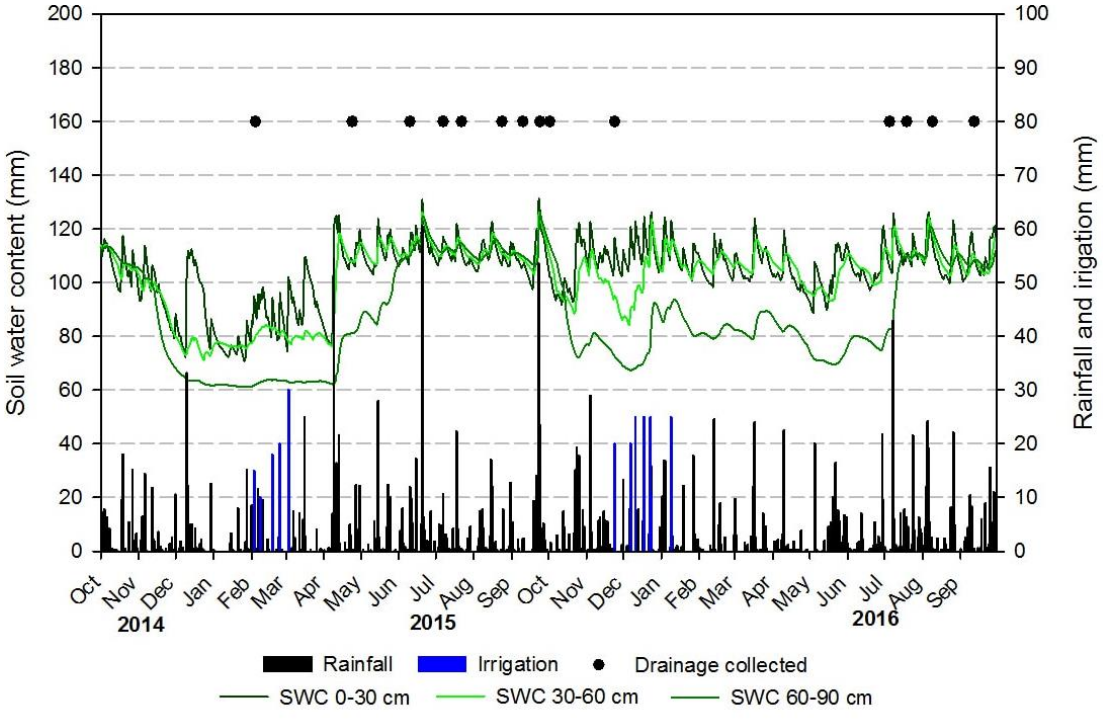

Figure 46. Summary of daily rainfall, irrigation and modelled soil water content (0–30 cm, 30–60 cm and 60–90 cm) from 1 October 2014, Site 9 — Hawke's Bay. Fluxmeters were installed on 4 September 2014.

3.9.5 Losses of N and P in drainage water

Year 1 (1 October 2014 to 30 September 2015)

Drainage samples were collected on eight occasions in the first year following installation of the fluxmeters. Total drainage volume was 62 mm (Figure 47b).

Nitrate-N and ammonium-N concentrations in drainage for this period averaged 9.5 mg/L and 1.7 mg/L respectively (Figure 47b). Nitrate-N concentrations tended to increase over the monitoring period and peaked at 21.2 mg/L in late September 2015 while ammonium-N concentrations remained low for the duration of the period (< 3.5 mg/L). Net mineral N losses from the system totalled 7.3 kg N/ha (Figure 47c) with the majority of N lost as nitrate-N (6.5 kg N/ha).

Total P and DRP concentrations averaged 0.43 mg/L and 0.16 mg/L respectively (Figure 48b). Measured P losses from the system were low, totalling 0.21 kg P/ha with DRP loss accounting for 0.06 kg P/ha (Figure 48c).

Year 2 (1 October 2015 to 30 September 2016)

Drainage samples were collected on six occasions in the second year following installation of the fluxmeters. Total drainage volume was 66 mm (Figure 47b).

Nitrate-N and ammonium-N concentrations in drainage for this period averaged 21.7 mg/L and 0.02 mg/L respectively (Figure 47b). Nitrate-N concentrations were higher than those observed in Year 1 (9.5 mg/l) and consequently net mineral N losses from the system were higher at 17.4 kg N/ha (Figure 47c). Nitrate-N concentrations peaked in early July 2016 (27.4 mg/L).

Total P and DRP concentrations averaged 0.10 mg/L and 0.05 mg/L respectively (Figure 48b). Measured P losses from the system were minimal (0.06 kg P/ha; Figure 48c).

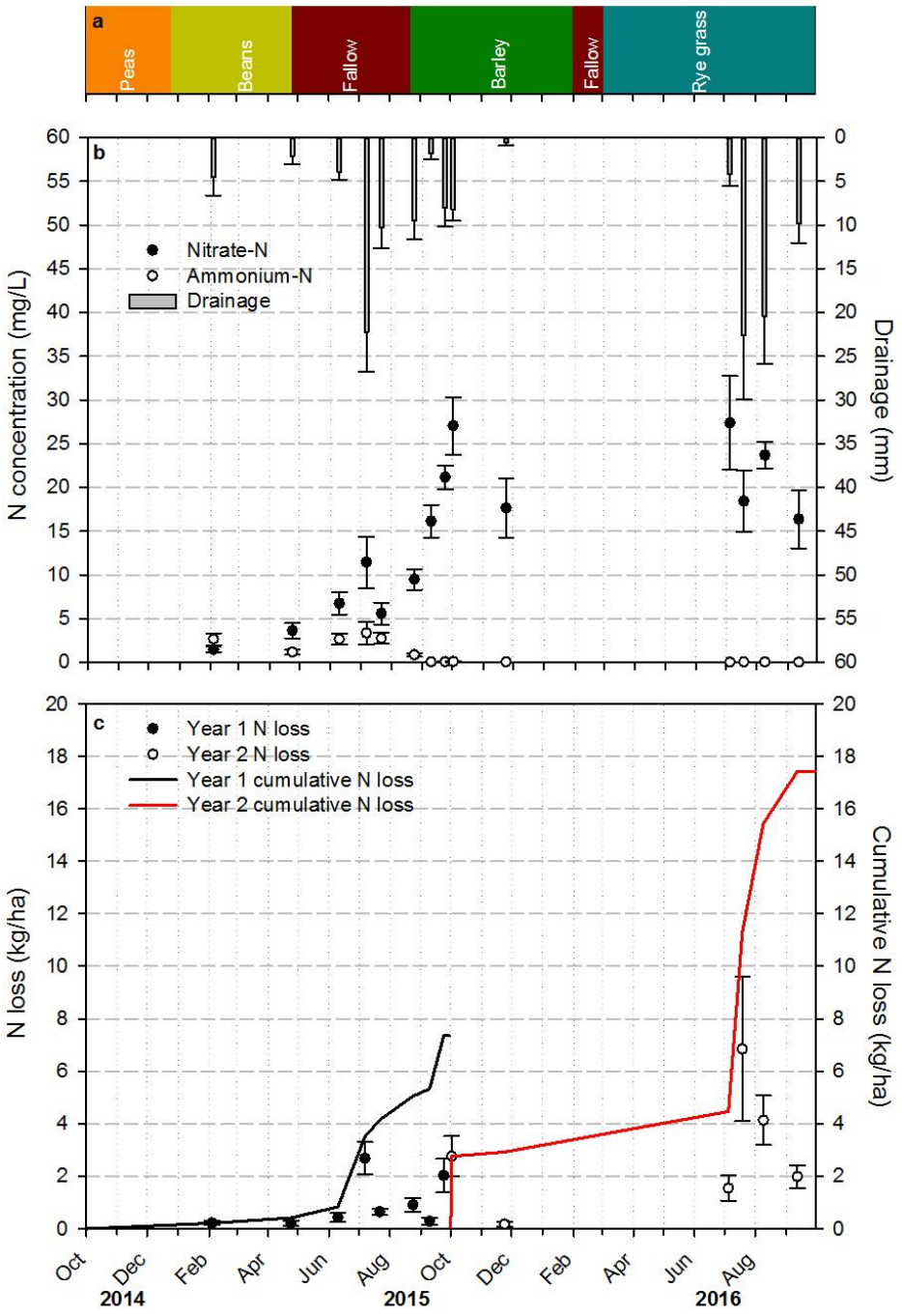

Figure 47. Summary of crop sequence (a), measured drainage and inorganic N concentrations (nitrate-N and ammonium-N) in drainage (b) and measured system losses of inorganic N in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) (c) Site 9 — Hawke's Bay. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: nitrate-N: 0.02 mg/L; ammonium-N: 0.01 mg/L. Fluxmeters were installed on 4 September 2014.

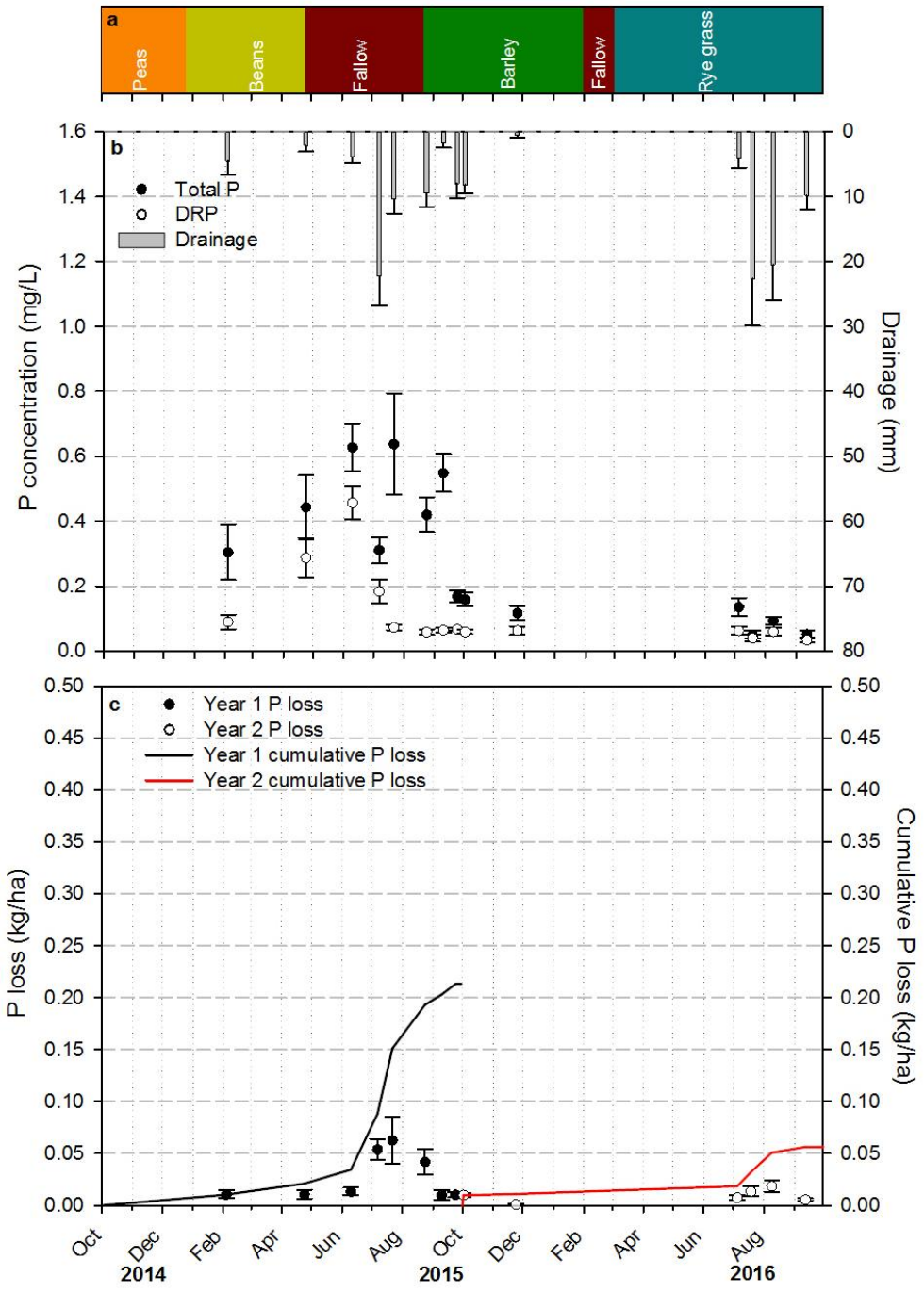

Figure 48. Summary of crop sequence (a), measured drainage and P concentrations (total P and DRP) in drainage (b) and measured system losses of total P in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) (c) Site 9 — Hawke's Bay. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: Total P: 0.02 mg/L; DRP: 0.001 mg/L. Fluxmeters were installed on 4 September 2014.

3.10 Site 10 — Matamata/Pukekohe

3.10.1 Background site and crop management history

Site 10 is located near Matamata on a mixed cropping and livestock grazing enterprise. Soil type a Waihou silt loam. Fluxmeters were installed at the site in May 2015. Key site characteristics are listed in Table 20.

Table 20. Summary of key farm and site characteristics, Site 10 — Matamata.

Location	Matamata
Farming system	Mixed cropping, livestock grazing
Topography	Gentle rolling
Soil type	Waihou silt loam
Key soil characteristics[1]	Soil order: Typic orthic allophanic Texture: Loam over sandy loam Topsoil bulk density: 0.78 g/cm^3 Subsoil bulk density: 0.86 g/cm^3 Drainage class: Well drained N leaching vulnerability: Low
Previous land use history	Converted from dairy pasture to mixed cropping in 2014; the first crop following conversion was potatoes.
Fluxmeter installation date	13 May 2015
Irrigation infrastructure	Centre pivot

[1]A full description of the Waihou silt loam is available online at https://smap.landcareresearch.co.nz/home. Listed characteristics are taken from S-MAP factsheets and are not based on measured site values.

Since installation of the fluxmeters there have been three crops including Italian ryegrass, potatoes and onions (Table 21). Italian ryegrass was sown in May 2015, sprayed off in September 2015 and the site sown with potatoes in October 2015. Following harvesting of the potato crop in March 2016, the site remained fallow until July when onions (the current crop) were planted. Respective N and P inputs have totalled 18 kg N/ha and 0 kg P/ha (Italian ryegrass), 291 kg N/ha and 120 kg P/ha (potato) and 44 kg N/ha and 96 kg P/ha (onion) (Table 21).

Table 21. Summary of crop management practices since fluxmeter installation (13 May 2015), Site 10 – Matamata.

Crop management practices	Sequence 1 — Italian ryegrass	Sequence 2 — Potatoes	Sequence 3 — Onions
Variety	'Tama'	'Russet ranger'	Information not yet available
Planting population	25 kg/ha	41,500 seeds/ha	710,000 plants/ha
Planting date	10 May 2015	14 October 2015	3 July 2016
Harvest date[1]	19 September[2]	15 March 2016	Current crop
Cultivation practices	Disking followed by sowing and rolling	Hoeing followed by deep ripping and power harrow	Shallow rip followed by power harrow and bed formation
Fertiliser practices (product)[3]	40 kg/ha Urea (P)	750 kg/ha potato pre-plant mix (B) 1500 kg/ha potato planting mix (P) 320 kg/ha Sustain N (S)[4]	5 t/ha lime (B) 5 t/ha lime (P) 800 kg/ha serpentine super (P) 250 kg/ha DAP (S)
Summed N and P (elemental)	N = 18 kg/ha P = 0 kg/ha	N = 291 kg/ha P = 120 kg/ha	N = 44 kg/ha P = 96 kg/ha
Stock type	No stock	No stock	No stock
Stock density	-	-	-
Additional stock information	-	-	-

[1]Commercial harvest date. [2] Date ryegrass was sprayed off. [3]B = base application, P = planting application, S= side dressing application(s). [4]Split over four applications between December 2015 and February 2016.

3.10.2 General weather conditions

Year 1 (1 October 2014 to 30 September 2015)

Rainfall for the Year 1 period was 1043 mm, 8% less than the long-term average for the region (1131 mm) (Figure 49a). Over the winter and spring period (June to November 2015), rainfall totalled 575 mm, comparable with the long-term average for this period (570 mm).

Mean air temperature for the 12 month period was 12.8°C, cooler than the long-term average for the region (13.5°C) (Figure 49b). Solar radiation totalled 5469 MJ/m^2, slightly higher than the long-term average of 5290 MJ/m^2 (Figure 49c).

Year 2 (1 October 2015 to 30 September 2016)

Rainfall for the Year 2 period was 1050 mm, 7% less than the long-term average for the region (Figure 49a). However the winter and spring period (June to November 2016) was wetter than average with 688 mm recorded compared to the long-term average of 570 mm for this period.

Air temperature averaged 13.6°C for the 12 month period, comparable to the long-term average (13.5°C) (Figure 49b). Solar radiation totalled 5013 MJ/m^2, slightly lower than the long-term average for region (Figure 49c).

3.10.3 Soil nitrogen and phosphorus fertility levels

Soil samples for N and P fertility analyses were taken during installation of the fluxmeters in May 2015, two weeks after planting of the potato crop in October 2015 and one week after planting of the onion crop in July 2017.

Mineral N (0–100 cm)

Mineral N concentrations were high for all sampling occasions, ranging between 298 and 367 kg N/ha, with the majority of this nitrogen present in the nitrate-N form (88–97%). Samples takes in October were taken 2 weeks after a base application of potato pre-plant mix (Table 21) and consequently high mineral N concentrations for this sample reflect this N fertiliser application. However, samples taken in May 2015 and July 2016 were taken prior to the application of N fertiliser and consequently reflect residual mineral N in the soil profile at the end of the respective crop sequences.

AMN (0–100 cm)

AMN concentrations were moderate for the May 2015 and October 2015 samples (126–169 kg N/ha) and high for the July 2016 samples (337 kg N/ha). Overall values were within or above the normal concentrations suggested for Italian ryegrass, potato and onion production (100–150 kg N/ha) (Figure 50a).

Olsen P (0–20 cm)

Olsen P concentrations were moderate for all sampling occasions (34–42 mg/L) and within normal concentrations suggested for Italian ryegrass (20–30 mg/L) and potato production (30–60 mg/L) but slightly below normal concentrations for onion production (45–90 mg/L) (Figure 50b).

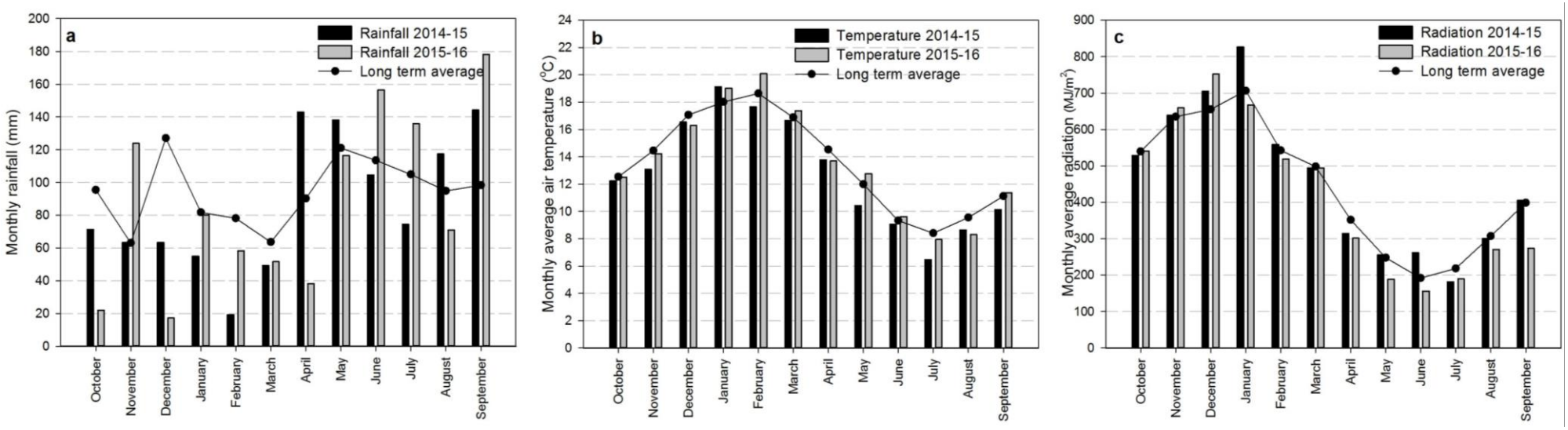

Figure 49. Monthly (a) rainfall (mm), (b) average air temperature (°C) and average solar radiation (MJ/m^2) for 1 October 2014 to 30 September 2016 at Matamata (rainfall and temperature; NIWA Station 25820) and Toenepi (radiation; NIWA Station 31620). Long-term climate data (2001–14) are presented for the Matamata and Toenepi stations.

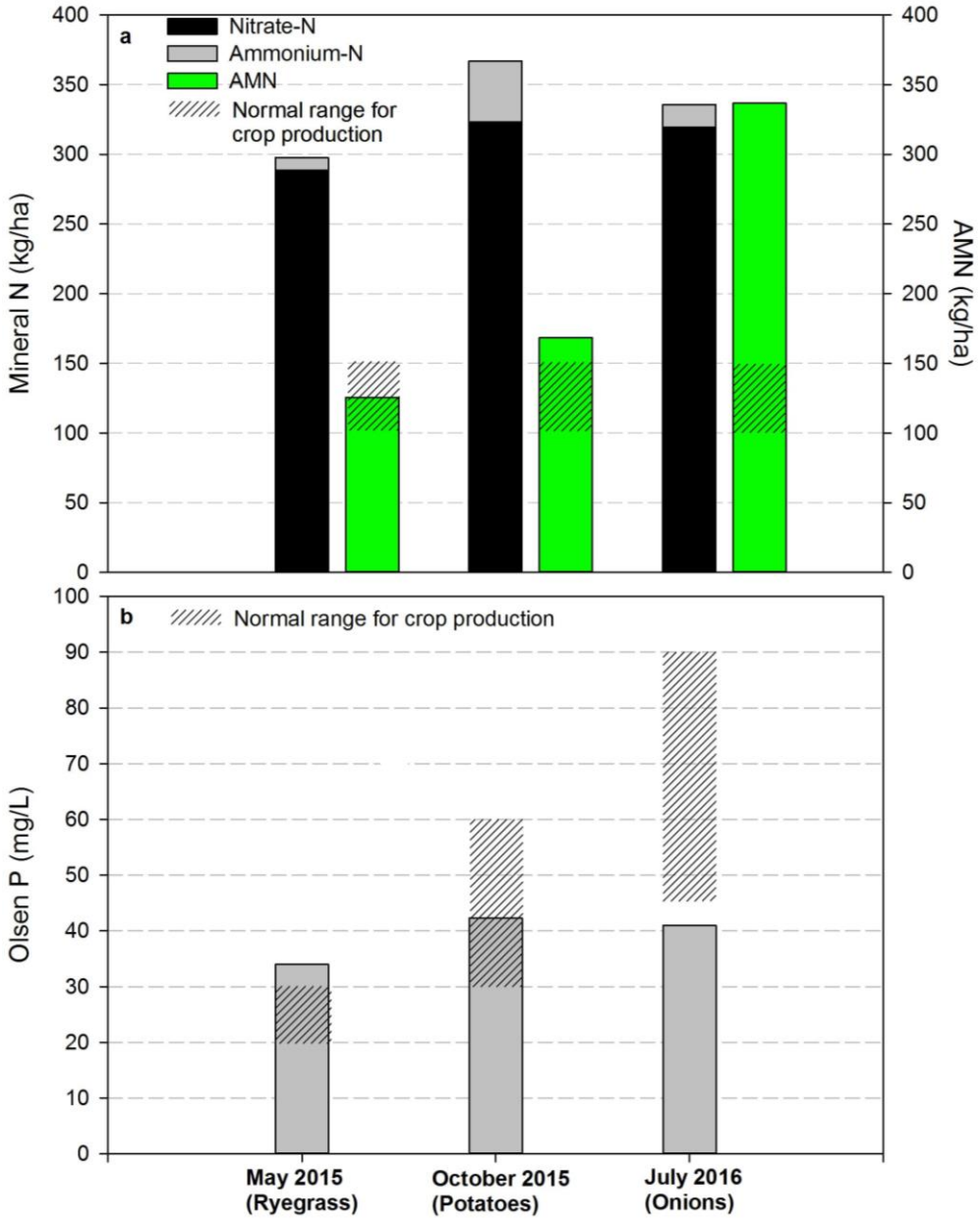

Figure 50. Soil mineral N and AMN (0–100 cm depth) (a) and Olsen P (0–20 cm depth) (b) at Site 10 — Matamata for samples taken in May 2015, October 2015 and July 2016. Normal ranges suggested for crop production are provided by Hill Laboratories (http://www.hill-laboratories.com/page/pageid/2145845703/Crop_Guides).

3.10.4 Soil water balance

Year 1 (1 October 2014 to 30 September 2015)

The soil water balance for Site 10 is shown in Figure 51. Rainfall and irrigation for the Year 1 period totalled 1043 mm and 80 mm respectively. There were three rainfall events over 50 mm, one in mid-April 2015 (77 mm over 1 day), one in late-May (62 mm over 3 days) and one in mid-September (81 mm over 3 days). The range in individual irrigation application volumes was 25 to 30 mm.

Modelled soil water contents increased to above 150 mm at all depths from mid-April 2015 and remained at elevated levels for the duration of the late autumn through to early spring period. Drainage samples were collected from mid-July 2015 onwards.

Year 2 (1 October 2015 to 30 September 2016)

Rainfall and irrigation for the Year 2 period totalled 1050 mm and 120 mm respectively. There were consistent periods of rainfall over the late autumn to early spring period (May to September 2016) with a number of events over 50 mm including 96 mm over 2 days in late June and 92 mm over 5 days in late September. There were four irrigation applications between mid-December and late January (irrigation volumes ranged from 25 to 35 mm per application).

Modelled soil water contents remained high at all depths (> 125 mm) through the spring period (September to November) before declining over the summer through to mid-autumn period (December to March) in response to less frequent rainfall and crop water use. Soil water contents increased to high levels from mid-June onwards. Six drainage samples were collected, three between late October 2015 and mid-January 2016 and three between mid-July and mid-September 2016.

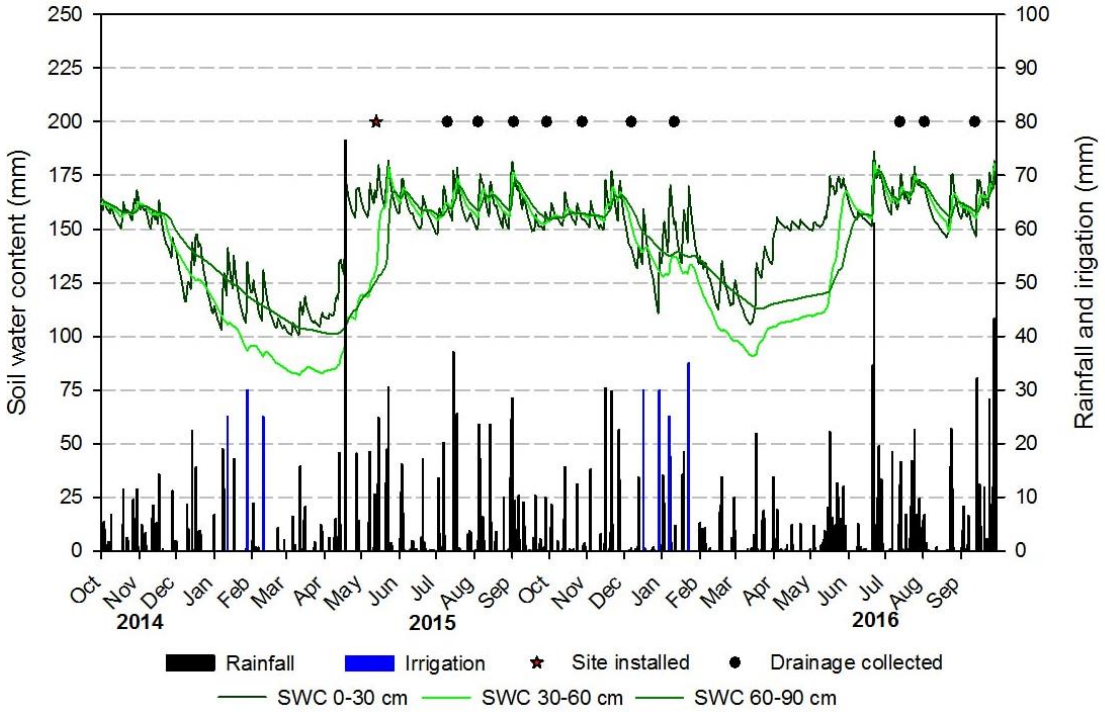

Figure 51. Summary of daily rainfall, irrigation and modelled soil water content (0–30 cm, 30–60 cm and 60–90 cm) from 1 October 2014, Site 10 — Matamata.

3.10.5 Losses of N and P in drainage water

Year 1 (1 October 2014 to 30 September 2015)

Drainage samples were collected on four occasions in the first year following installation of the fluxmeters. Total drainage volume was 150 mm (Figure 52b).

Nitrate-N and ammonium-N concentrations in drainage for this period averaged 17.2 mg/L and 0.4 mg/L respectively (Figure 52b). Nitrate-N concentrations were fairly consistent over the monitoring period ranging from 15.9 to 19.1 mg/L, while ammonium-N concentrations remained low (< 0.8 mg/L). Measured mineral N losses from the system totalled 29.8 kg N/ha (Figure 52c) with the majority of N lost as nitrate-N (29.5 kg N/ha).

Total P and dissolved DRP concentrations averaged 0.08 mg/L and 0.07 mg/L respectively (Figure 53b). Net P losses from the system were minimal, totalling 0.07 kg P/ha (Figure 53c).

Year 2 (1 October 2015 to 30 September 2016)

Drainage samples were collected on six occasions in the second year following installation of the fluxmeters. Total drainage volume was 112 mm (Figure 52b).

Nitrate-N and ammonium-N concentrations in drainage for this period averaged 14.5 mg/L and 0.5 mg/L respectively (Figure 52b). Nitrate-N concentrations remained relatively consistent over the monitoring period (range was 10.4 to 18.2 mg/L). Measured mineral N losses from the system totalled 12.4 kg N/ha (Figure 52c) with N lost almost entirely as nitrate-N.

Total P and DRP concentrations over this period remained low, averaging 0.04 mg/L and 0.02 mg/L respectively (Figure 33b). Consequently, measured P losses from the system were minimal (< 0.05 kg P/ha; Figure 33c).

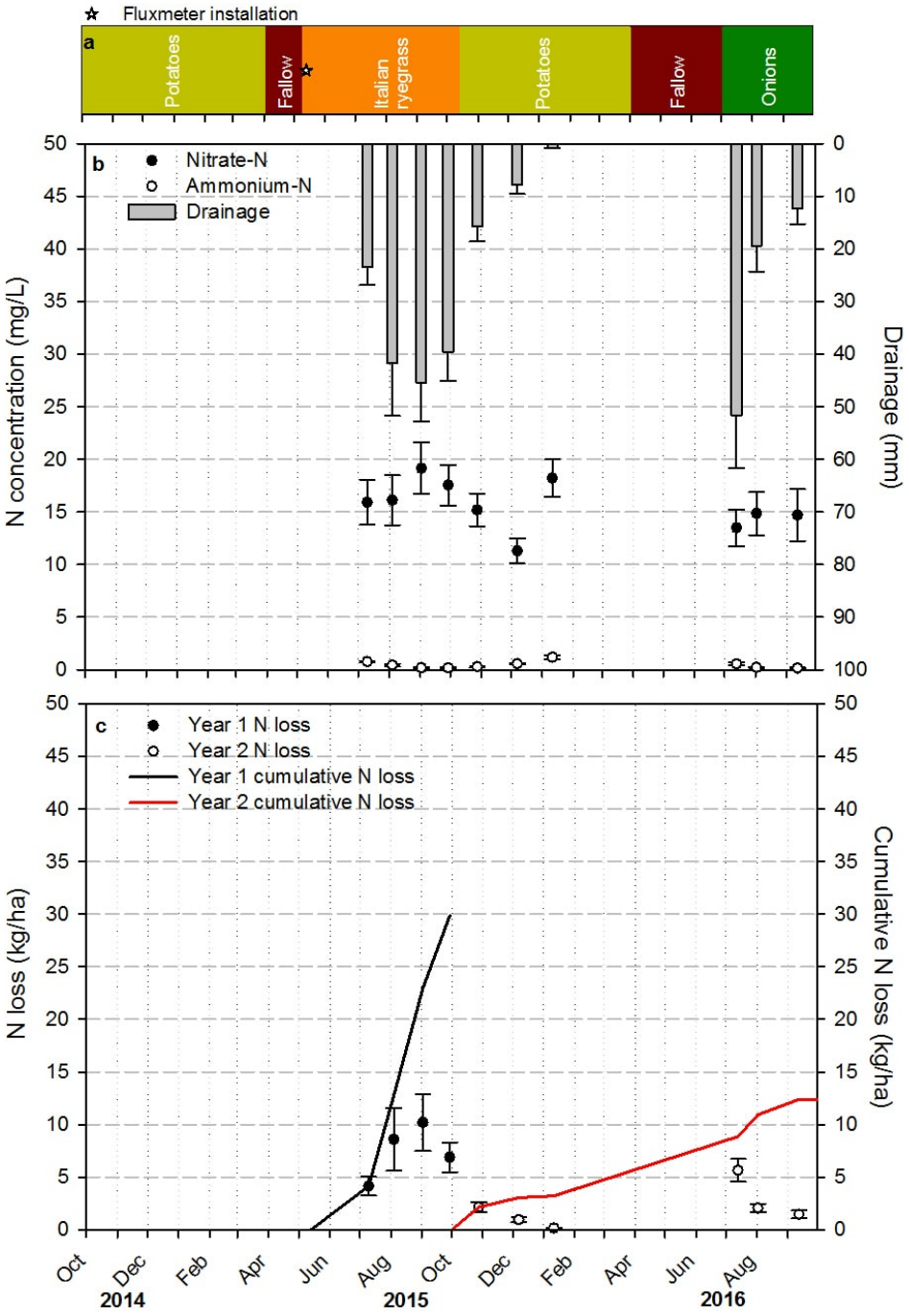

Figure 52. Summary of crop sequence (a), measured drainage and inorganic N concentrations (nitrate-N and ammonium-N) in drainage (b) and measured system losses of inorganic N in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) (c) Site 10 — Matamata. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: nitrate-N: 0.02 mg/L; ammonium-N: 0.01 mg/L.

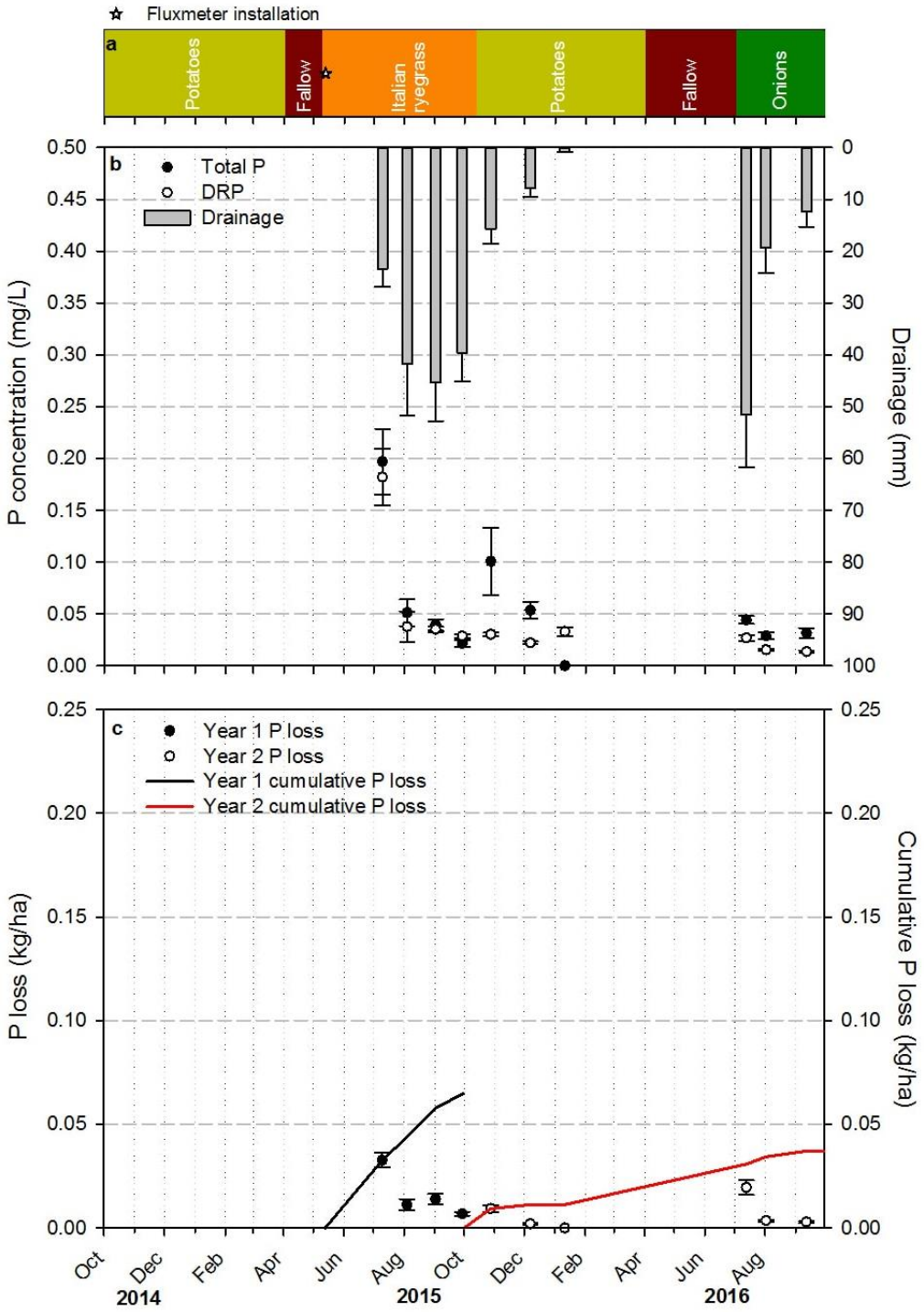

Figure 53. Summary of crop sequence (a), measured drainage and P concentrations (total P and DRP) in drainage (b) and measured system losses of total P in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) (c) Site 10 — Matamata. Mean drainage is calculated from the volume of leachate collected at each sampling event, corrected for the surface area of the fluxmeters. Bars around each point represent the standard error of the mean. Lower limit of detections: Total P: 0.02 mg/L; DRP: 0.001 mg/L.

3.11 Site 11 — Matamata/Pukekohe

3.11.1 Background site and crop management history

Site 11 is located near Pukekohe on an intensive vegetable cropping enterprise. Soil type is a Patumahoe clay loam. Fluxmeters were installed at the site in March 2015. Key site characteristics are described in Table 22.

Table 22. Summary of key farm and site characteristics, Site 11 — Pukekohe.

Location	Pukekohe
Farming system	Intensive vegetable production
Topography	Flat
Soil type	Patumahoe clay loam
Key soil characteristics[1]	Soil order: Mottled orthic granular Texture: Loam over clay Topsoil bulk density: 1.09 g/cm^3 Subsoil bulk density: 1.09 g/cm^3 Drainage class: Imperfectly drained N leaching vulnerability: Medium
Previous land use history	For past 10 years the site has been in an onion-potato-green crop rotation
Fluxmeter installation date	10 March 2015
Irrigation infrastructure	Gun/lateral

[1]A full description of the Patumahoe clay loam is available online at https://smap.landcareresearch.co.nz/home. Listed characteristics are taken from S-MAP factsheets and are not based on measured site values.

Since installation there have two crops including potato sown in June 2015 and harvested in November 2015 and the current onion crop sown in May 2016 (Table 23). Respective N and P inputs have totalled 318 kg N/ha and 30 kg P/ha (potato) and 136 kg N/ha and 76 kg P/ha (onion) (Table 23).

Table 23. Summary of crop management practices since fluxmeter installation (10 March 2015), Site 11 — Pukekohe.

Crop management practices	Sequence 1 — Potatoes	Sequence 2 — Fallow	Sequence 3 — Onions
Variety	'Victoria'	-	'Ayoba'
Planting population	46,000 seeds/ha	-	520,000 plants/ha
Planting date	9 June 2015	-	15 May 2016
Harvest date[1]	15 November 2015	-	Current crop
Cultivation practices	Deep rip followed by power harrow and bed formation	-	Ripped followed by power harrow and planting
Fertiliser practices (product)[2]	1000 kg/ha Green Complex (P) 300 kg/ha Ammonium sulphate (P) 500 kg/ha CAN (S)[3]	-	150 kg/ha DAP (P) 550 kg/ha Hydro complex (S)[4] 270 kg/ha Yara Actyva (S)
Summed N and P (elemental)	N = 318 kg/ha P = 30 kg/ha	-	N = 136 kg/ha P = 76 kg/ha
Stock type	No stock	-	No stock
Stock density	-	-	-
Additional stock information	-	-	-

[1] Commercial harvest date. [2]B = base application, P = planting application, S= side dressing application(s). [3]Split over two applications between August and September 2015. [4]Split over two applications between August and September 2016.

3.11.2 General weather conditions

Year 1 (1 October 2014 to 30 September 2015)

Rainfall for the Year 1 period was 1166 mm, comparable with the long-term average for the region (1183 mm) (Figure 54a). Rainfall for the winter and spring period (June to November) was 665 mm, also comparable with the long-term average for this period (648 mm).

Mean air temperature was 14.3°C, slightly lower than the long-term average (14.6°C) (Figure 54b) while solar radiation totalled 5166 MJ/m^2 was comparable to the long-term average of 5215 MJ/m^2 (Figure 54c).

Year 2 (1 October 2015 to 30 September 2016)

Rainfall for the Year 2 period was 1273 mm, 8% higher than long-term average for the region (Figure 54a). The winter to early spring period (June to September 2016) was particularly wet with 619 mm recorded, 33% higher than long-term average for this period (648 mm).

Mean air temperature over the 12 month period was 14.9°C, slightly warmer than the long-term average (Figure 54b). Solar radiation totalled 4956 MJ/m^2, slightly lower than the long-term average (Figure 54c).

3.11.3 Soil nitrogen and phosphorus fertility levels

Soil samples for N and P fertility analyses were taken during installation of the fluxmeters in March 2015, one week after sowing of the potato crop in June 2015 and 7 weeks after sowing of the onion crop in July 2016.

Mineral N (0–100 cm)

Samples taken in March 2015 and June 2015 had high concentrations of mineral N (212 kg N/ha and 319 kg N/ha respectively) (Figure 55a). For the March samples, the majority of mineral N was present in the nitrate-N form (94%), whereas for the June samples ammonium N concentrations were elevated (54% of mineral N) and reflected applications of ammonium-based fertiliser at planting. Samples taken in July 2016 had moderate concentrations of mineral N (145 kg N/ha) with 96% of this nitrogen present in the nitrate-N form.

AMN (0–100 cm)

AMN concentrations were low in the March 2015 and June 2015 samples (60 to 77 kg N/ha) and below the normal concentrations suggested for potatoes (100–150 kg N/ha) (Figure 55a). AMN concentrations were moderate in the July 2015 samples (184 kg N/ha) and within normal concentrations suggested for onion production (100–150 kg N/ha).

Olsen P (0–20 cm)

Olsen P concentrations were very high for all sampling occasions (148–213 mg/L) and well above normal concentrations suggested for potato (30–60 mg/L) and onion (45–90 mg/L) production (Figure 55b).

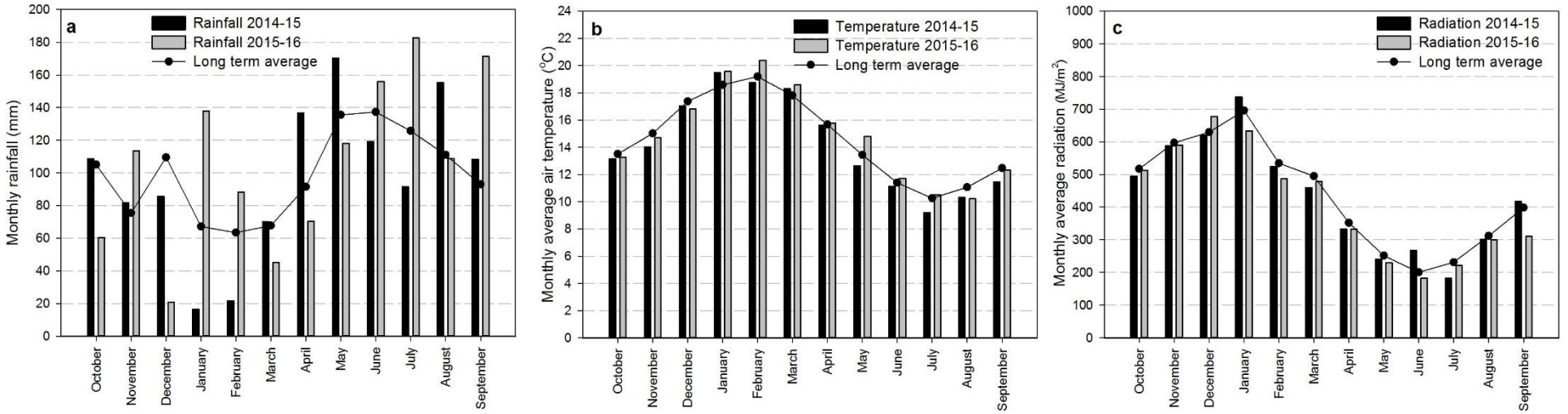

Figure 54. Monthly (a) rainfall (mm), (b) average air temperature (°C) and average solar radiation (MJ/m^2) for 1 October 2014 to 30 September 2016 at Pukekohe (NIWA Station 1962). Long-term climate data (2001–14) are presented for the Pukekohe station.

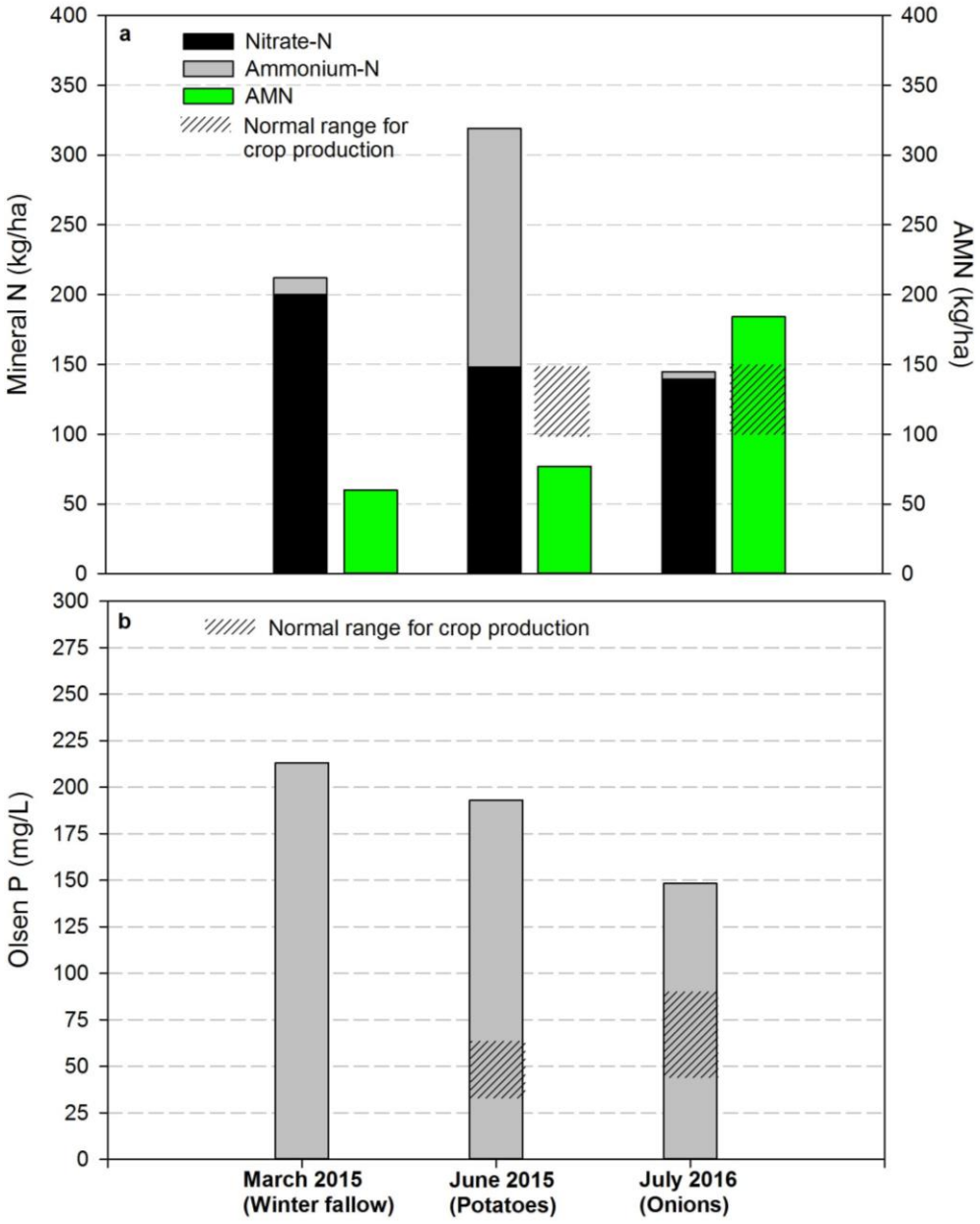

Figure 55. Soil mineral N and AMN (0–100 cm depth) (a) and Olsen P (0–20 cm depth) (b) at Site 11 — Pukekohe for samples taken in March 2015, June 2015 and July 2016. Normal ranges suggested for crop production are provided by Hill Laboratories (http://www.hill-laboratories.com/page/pageid/2145845703/Crop_Guides).

3.11.4 Soil water balance

Year 1 (1 October 2014 to 30 September 2015)

The soil water balance for Site 11 is shown in Figure 56. Rainfall and irrigation for the Year 1 period totalled 1166 mm and 0 mm respectively. There was frequent and often heavy rainfall over the late autumn to early spring period (April to September 2015) and consequently modelled soil water contents for all depths remained elevated over this period (> 120 mm). Drainage collection commenced in mid-July 2015.

Year 2 (1 October 2015 to 30 September 2016)

Rainfall and irrigation for the Year 2 period totalled 1273 mm and 0 mm respectively. As in Year 1, there was frequent and often heavy rainfall over the late autumn to early spring period (April to September 2016) with a number of significant rainfall events including 70 mm over 2 days in late August and 110 mm over a 10 day period in mid-September.

Modelled soil moisture contents decreased for all depths over the spring period (September November 2015) before increasing to elevated levels (> 110 mm) in late November from where they remained elevated for the remainder of the monitoring period. Four drainage samples were collected, one in early March and three between July and September.

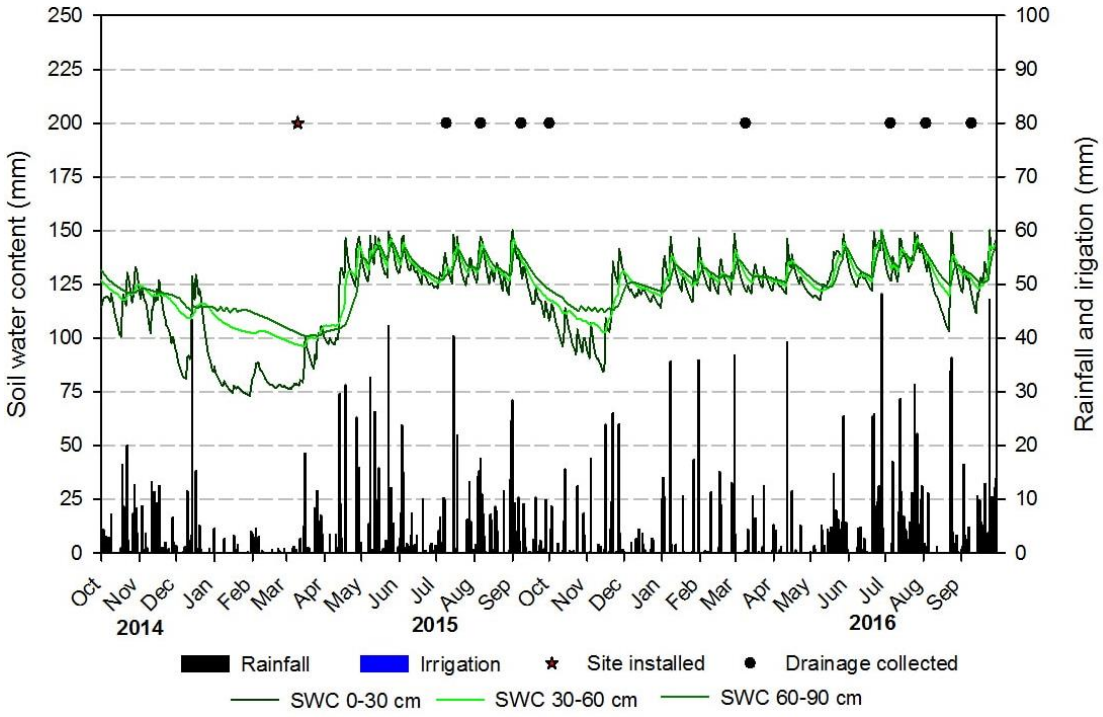

Figure 56. Summary of daily rainfall, irrigation and modelled soil water content (0–30 cm, 30–60 cm and 60–90 cm) from 1 October 2014, Site 11 — Pukekohe.

3.11.5 Losses of N and P in drainage water

There have been a total of eight drainage samplings since installation of the fluxmeter units in March 2015. For six of these samplings, volumes collected in the fluxmeter units were considerably higher than those predicted by the soil water balance and consequently have not been used to date to calculate N and P losses (only concentrations are provided below). The cause of increased sample volumes is not yet clear, however it is appears unlikely that this is due to groundwater intrusion due to the elevated location of the site relative to the surrounding countryside and little evidence of gleying in the soil profile. Furthermore, measured nitrate concentrations remained relatively high for the duration of the monitoring period (19 to 50 mg/L) suggesting that captured water originated from the overlying soil profile as opposed to more diluted groundwater.

An alternative approach being considered is to estimate losses using a combination of measured N and P concentrations and modelled drainage volumes (as is the common approach for measuring losses using devices like suction cups). To ensure a high level of confidence in the predictions, additional soil physical measurements are being collected from the site. These will be used in the soil water balance model to predict drainage volumes. An onsite rain gauge will also be installed to accurately quantify inputs from rainfall and irrigation.

Year 1 (1 October 2014 to 30 September 2015)

Samples were collected on four occasions in the first year following installation of the fluxmeters (Figure 57b). Nitrate-N and ammonium-N concentrations in drainage for this period averaged 33.5 mg/L and 0.25 mg/L respectively (Figure 57b). Nitrate-N concentrations ranged from 22.8 to 50.0 mg/L and peaked in late September while ammonium-N concentrations remained consistently low (< 1 mg/L). Total P and DRP concentrations averaged 0.03 mg/L and 0.03 mg/L respectively (Figure 57c).

Year 2 (1 October 2015 to 30 September 2016)

Samples were collected on four occasions in the second year following installation of the fluxmeters (Figure 57b). Nitrate-N and ammonium-N concentrations in drainage for this period averaged 22.0 mg/L and 0.04 mg/L respectively (Figure 57b). Nitrate-N concentrations appeared to decline from high levels in spring 2015 (50.0 mg/L) to moderate levels (19.0 mg/L) in spring 2016. Total P and DRP concentrations over this period remained low, averaging 0.03 mg/L and 0.02 mg/L respectively (Figure 57c).

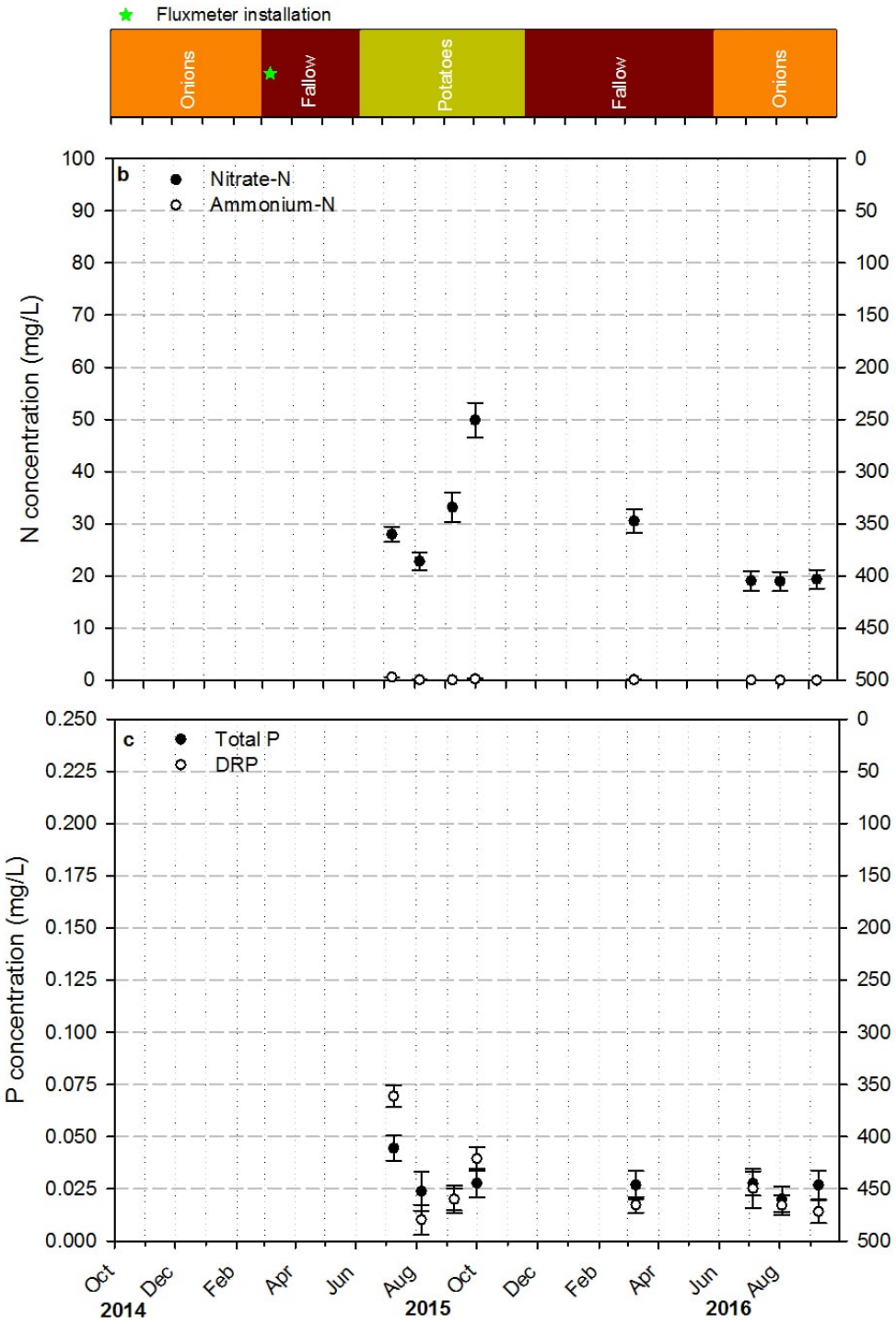

Figure 57. Summary of crop sequence (a) measured inorganic N concentrations (nitrate-N and ammonium-N) (b) and measured P concentrations (total P and DRP) (c) in drainage for Year 1 (1 October 2014 to 30 September 2015) and for Year 2 (1 October 2015 to 30 September 2016) at Site 11 — Pukekohe. Bars around each point represent the standard error of the mean. Lower limit of detections: nitrate-N: 0.02 mg/L; ammonium-N: 0.01 mg/L; total P: 0.02 mg/L; DRP: 0.001 mg/L.

3.12 Site 12 — Matamata/Pukekohe

3.12.1 Background site and crop management history

Site 12 is located near Tuakau on a mixed cropping and livestock grazing enterprise. Soil type is a Patumahoe clay loam. Fluxmeters were installed at the site in April 2015. Key site characteristics are described in Table 24.

Table 24. Summary of key farm and site characteristics, Site 12 — Pukekohe.

Location	Tuakau
Farming system	Mixed cropping, livestock
Topography	Gently sloping
Soil type	Patumahoe clay loam
Key soil characteristics[1]	Soil order: Mottled orthic granular Texture: Loam over clay Topsoil bulk density: 1.09 g/cm^3 Subsoil bulk density: 1.09 g/cm^3 Drainage class: Imperfectly drained N leaching vulnerability: Medium
Previous land use history	Intensive vegetable production for more than 10 years.
Fluxmeter installation date	7 April 2015
Irrigation infrastructure	Gun

[1]A full description of the Patumahoe clay loam is available online at https://smap.landcareresearch.co.nz/home. Listed characteristics are taken from S-MAP factsheets and are not based on measured site values.

Following installation in April 2015, the site remained fallow over the winter and early spring period before being planted with potatoes in November 2015. The potato crop was harvested in April 2016. Respective N and P inputs for the potato crop have totalled 215 kg N/ha and 30 kg P/ha (Table 25). The site is currently fallow with a mustard crop due to be planted in November 2016.

Table 25. Summary of crop management practices since fluxmeter installation (7 April 2015), Site 12 — Pukekohe.

Crop management practices	Sequence 1 — Winter fallow	Sequence 2 — Potatoes	Sequence 3 — Fallow
Variety	-	'Rua'	Site currently fallow
Planting population	-	56,250	-
Planting date	-	2 November 2015	-
Harvest date[1]	-	28 April 2016	-
Cultivation practices	-	Subsoil ripping followed by power harrow and bed formation	-
Fertiliser practices (product)[2]	-	1000 kg/ha potato mix (P) 350 kg/ha CAN (S)[3]	-
Summed N and P (elemental)	-	N = 215 kg/ha P = 30 kg/ha[3]	-
Stock type	-	-	-
Stock density	-	-	-
Additional stock information	-	-	-

[1]Commercial harvest date. [2]B = base application, P = planting application, S= side dressing application(s). [3]Split over two applications between November 2015 and January 2016.

3.12.2 General weather conditions

Year 1 (1 October 2014 to 30 September 2015)

Rainfall for the Year 1 period was 1166 mm, comparable with the long-term average for the region (1183 mm) (Figure 58a). Rainfall for the winter and spring period (June to November) was 665 mm, also comparable with the long-term average for this period (648 mm).

Mean air temperature was 14.3°C, slightly lower than the long-term average (14.6°C) (Figure 58b) while solar radiation totalled 5166 MJ/m^2, comparable to the long-term average of 5215 MJ/m^2 (Figure 58c).

Year 2 (1 October 2015 to 30 September 2016)

Rainfall for the Year 2 period was 1273 mm, 8% higher than long-term average for the region (1183 mm) (Figure 58a). The winter to early spring period (June to September 2016) was particularly wet with 619 mm recorded, 33% higher than long-term average for this period (648 mm).

Mean air temperature over the 12 month period was 14.9°C, slightly warmer than the long-term average (Figure 58b) while solar radiation totalled 4956 MJ/m^2, moderately lower than the long-term average of 5215 MJ/m^2 (Figure 58c).

3.12.3 Soil nitrogen and phosphorus fertility levels

Soil samples for N and P fertility analyses were taken during installation of the fluxmeters in April 2015, following planting of the potato crop in November 2015 and in August 2016 while the site was fallow. The April 2015 and November 2015 samples were taken from the original site area while the August 2016 samples were taken from a replacement location in the same field but approximately 150 m further east.

Mineral N (0–100 cm)

Samples taken April 2015 and November 2015 had high concentrations of mineral N (186 to 541 kg N/ha) (Figure 59a). The very high concentrations of mineral N for the November 2015 samples reflected a recent application of base fertiliser. A high proportion of this mineral N was present in an ammonium-N form (45%). Samples taken in August 2016 from the replacement site also had high concentrations of mineral N (153 kg N/ha). Nitrate-N was the predominant form of mineral N for samples taken in April 2015 and August 2016 (84 to 89%).

AMN (0–100 cm)

Only the top 0–20 cm soil core was analysed for AMN in the April 2015 samples; AMN concentrations were low for this sample (49 kg N/ha), but consistent with samples taken from long-term intensive cropping soils (Figure 59a). AMN concentrations (0–100 cm depth) were moderate (100 to 153 kg N/ha) for samples taken in November 2015 and August 2016.

Olsen P (0-20 cm)

Olsen P concentrations were high for all sampling occasions (101–124 mg/L) and well above normal levels required for potato production (30–60 mg/L) (Figure 59b).

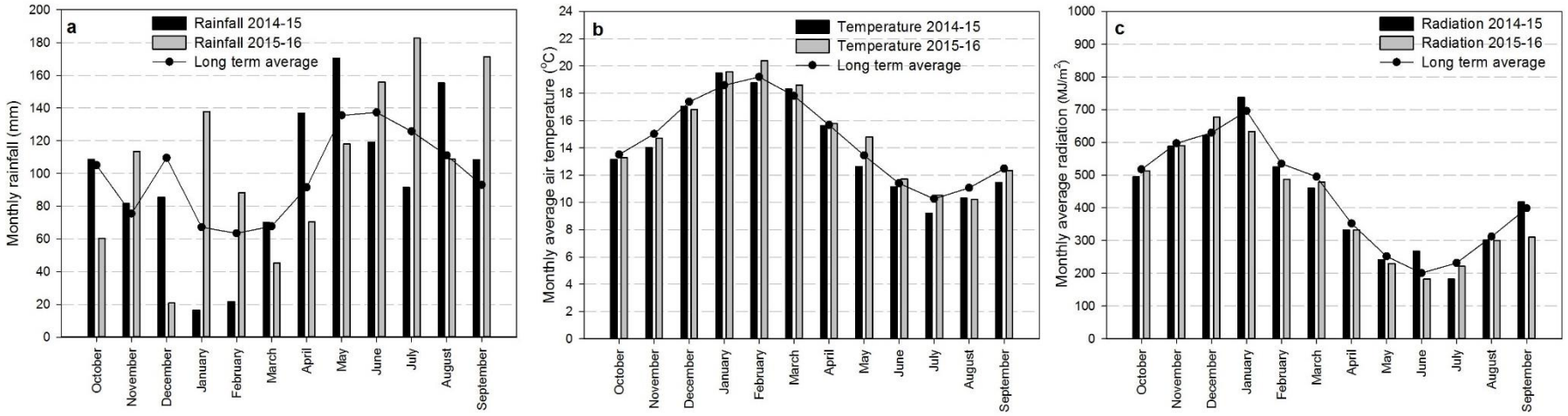

Figure 58. Monthly (a) rainfall (mm), (b) average air temperature (°C) and average solar radiation (MJ/m^2) for 1 October 2014 to 30 September 2016 at Pukekohe (NIWA Station 2006). Long-term climate data (2001–14) are presented for the Pukekohe station.

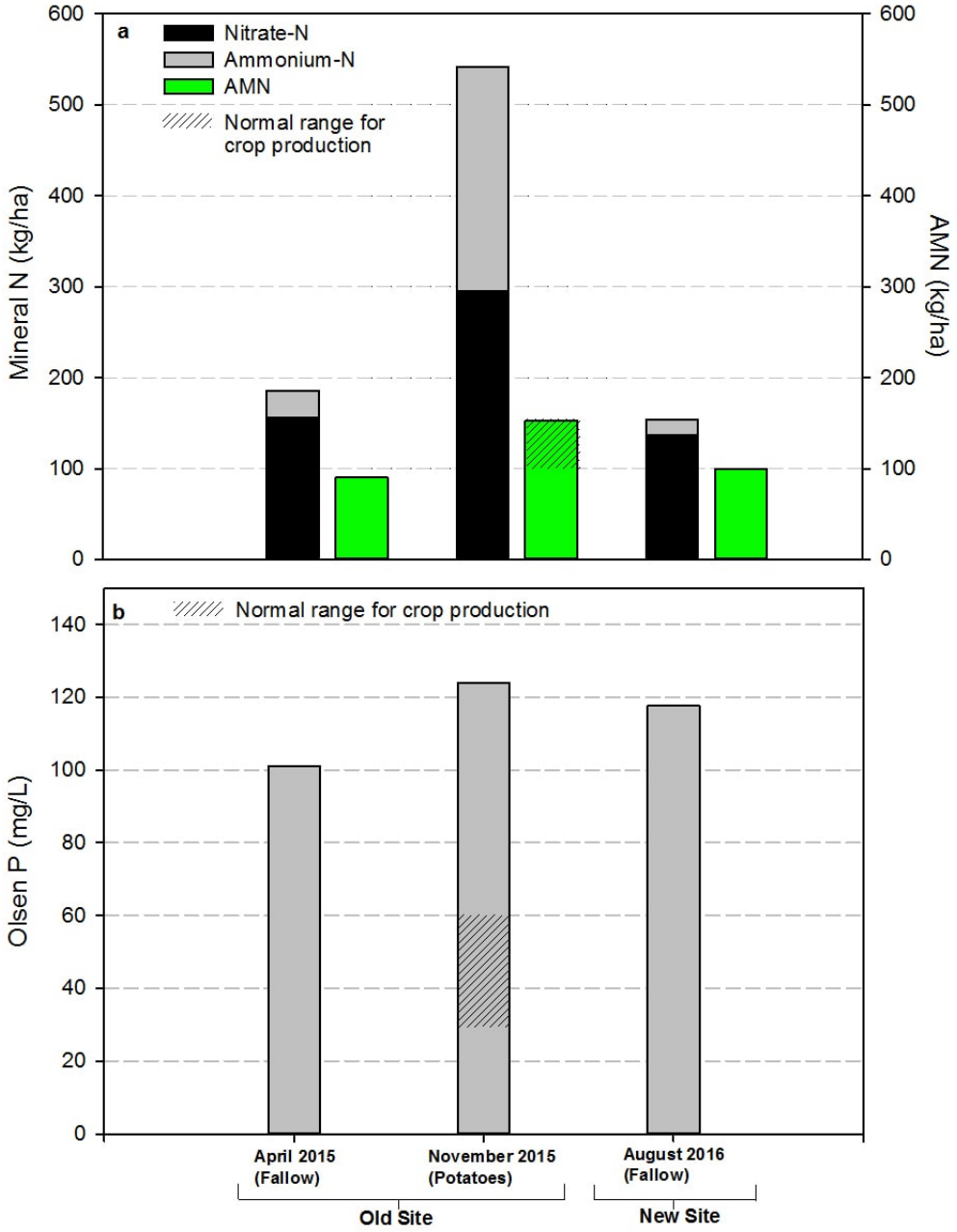

Figure 59. Soil mineral N (0–100 cm depth) and AMN (0–100 cm depth) (a) and Olsen P (0–20 cm depth) (b) at Site 12 — Pukekohe for samples taken from the old site in April and November 2015 and from the new site in August 2016. AMN concentrations for samples taken in April 2015 were determined only for the 0–20 cm depth.

3.12.4 Soil water balance

Year 1 (1 October 2014 to 30 September 2015)

The soil water balance for Site 12 is shown in Figure 60. Rainfall and irrigation for the Year 1 period totalled 1166 mm and 0 mm respectively. There was frequent and often heavy rainfall over the late autumn through to early spring period (1 April to 30 September 2015) and consequently modelled soil water contents for all depths remained elevated over this period (> 150 mm). Drainage was sampled on three occasions following installation of the fluxmeters in April 2015.

Year 2 (1 October 2015 to 30 September 2016)

Rainfall and irrigation for the Year 2 period totalled 1273 mm and 140 mm respectively.

The largest rainfall event occurred in late February where 51 mm was recorded in 4 days (Figure 60). There were four irrigations of 35 mm per application between mid-December and late February.

Modelled soil water contents decreased slightly over the summer period (December to February), but on the whole remained elevated for all depths (> 110 mm) for the duration of the monitoring period. Elevated soil moisture levels were consistent with frequent rainfall and irrigation. Five drainage samples were collected between October and February.

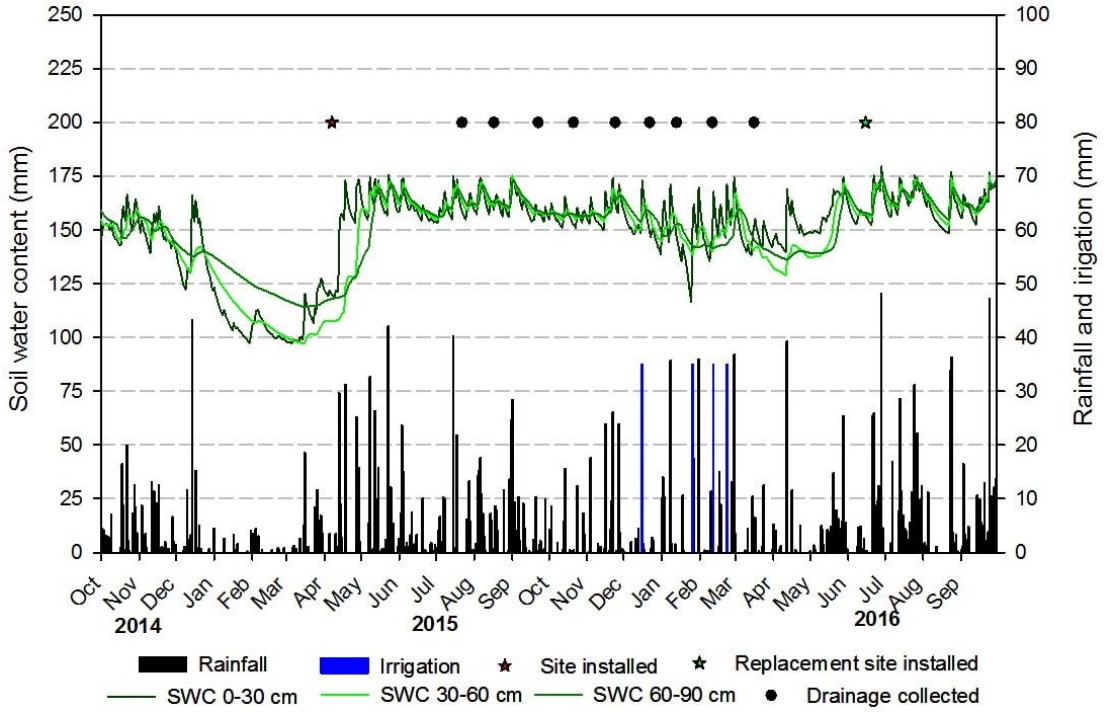

Figure 60. Summary of daily rainfall, irrigation and modelled soil water content (0–30 cm, 30–60 cm and 60–90 cm) 1 October 2014, Site 12 — Pukekohe.

3.12.5 Losses of N and P in drainage water

During the first year of monitoring, drainage volumes captured in the fluxmeters were considerably higher than those predicted by the soil water balance and consequently net losses of N and P have not been calculated. Elevated drainage volumes in the units was attributed to the presence of a compact ash layer at 80 to 90 cm through which the installation holes for the fluxmeter units were augured (Figure 62a). It was hypothesised that these holes drained water moving laterally across this layer resulting in captured volumes far greater than those predicted by the water balance model. The presence of Pukekawa School a short distance upslope of the site (Figure 62b) likely contributed to subsurface flow volumes through runoff from roof and tarmac surfaces. The experimental site was subsequently re-established in June 2016 in an area east of the current site and well away from the school (Figure 62b). No ash layer was evident in a subsequent soil profile examination of this area and the soil appeared to be free draining to a depth of at least 1 m.

Since reinstallation there has been one drainage sample collected in December 2016. While drainage volumes were similar to those predicted by the soil water balance, further sample collection over the coming months is required to confirm the success of the reinstall.

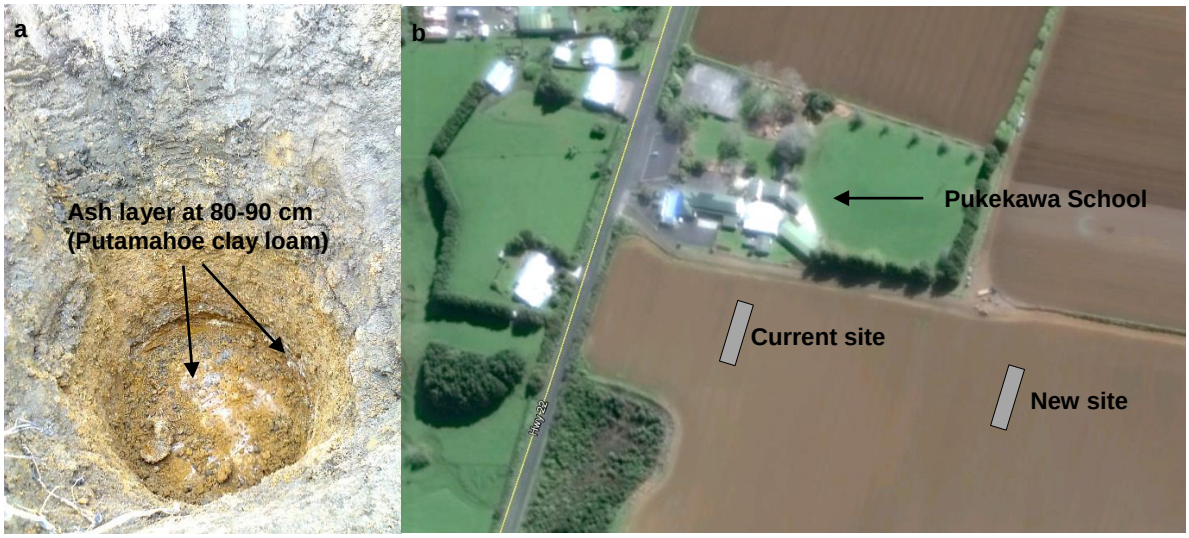

Figure 62. Picture of a Patumahoe clay loam soil profile (taken adjacent to the fluxmeter site) showing evidence of an ash layer at 80–90 cm (a) and location of fluxmeter Site 12 relative to Pukekawa school (b).

4 ACKNOWLEDGEMENTS

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APPENDIX 1. SUMMARY OF CROP SAMPLING PROTOCOLS USED ACROSS THE FLUXMETER NETWORK SITES

Crop	Sampling protocol
Barley	**Mid-season harvest:** Four samples were collected from each fluxmeter cluster. Each comprised a whole-plant sample harvested from a 0.52 m^2 quadrat cut at ground level. There was no separation of components. **Final harvest:** Four samples were collected from each fluxmeter cluster. Each comprised a whole-plant sample harvested from a 0.52 m^2 quadrat cut at ground level. The sample was separated into grain and straw components.
Clover (seed)	**Mid-season harvest:** No mid-season harvest was taken. **Final harvest:** Four samples were collected from each fluxmeter cluster. Each comprised a whole-plant sample harvested from a 0.27 m^2 quadrat cut at ground level. The sample was separated into seed and residue components.
Cabbage	**Mid-season harvest**: Four individual plants were taken from within each cluster area. There was no separation of components. **Final harvest**: One individual plant was taken from above each fluxmeter location giving four plant samples per cluster area. There was no separation of components.
Process beans	**Mid-season harvest**: Four samples were collected from each fluxmeter cluster. Each comprised a whole-plant sample harvested from a 0.25 m^2 quadrat cut at ground level. There was no separation of components. **Final harvest**: Four samples were collected from each fluxmeter cluster. Each comprised a whole-plant sample harvested from a 0.25 m^2 quadrat cut at ground level. The sample was separated into bean and leaf/stem residue components.
Process carrots	**Mid-season harvest**: Four samples were collected from each fluxmeter cluster. Each comprised a whole-plant sample (tops and roots) harvested from a 0.56 m^2 quadrat. There was no separation of components. **Final harvest**: Four samples were collected from each fluxmeter cluster. Each comprised a whole-plant sample (tops and roots) harvested from a 0.56 m^2 quadrat. The sample was separated into root and leaf/stem residue components.
Fodder beet	**Mid-season harvest**: Population was recorded from a single 2 m row within each cluster and a single whole plant taken for analyses of dry matter and N uptake. The sample was separated into crop and residue components. **Final harvest**: Population and total fresh weight were recorded from samples taken from two 6 m rows from within each cluster. A two plant subsample was taken for analyses of dry matter and N uptake. The sample was separated into crop and residue components.
Lettuce	**Mid-season harvest**: Three individual lettuces (above-ground component) were collected from a 0.69 m^2 area from each fluxmeter cluster. There was no separation of components. **Final harvest**: Three individual lettuces (above-ground component) were collected from a 0.69 m^2 area from each fluxmeter cluster. There was no separation of components.
Maize (grain)	**Mid-season harvest**: Four samples were collected from each fluxmeter cluster. Each comprised a whole-plant sample harvested from a 3.04 m^2 quadrat (2 m x 2 rows) cut at ground level. There was no separation of components. **Final harvest**: Four samples were collected from each fluxmeter cluster. Each comprised a whole-plant sample harvested from a 3.04 m^2 quadrat (2 m x 2 rows) cut at ground level. The sample was separated into cob and stover components.

Crop	Sampling protocol
Process peas	**Mid-season harvest**: Four samples were collected from each fluxmeter cluster. Each comprised a whole-plant sample harvested from a 0.25 m^2 quadrat cut at ground level. There was no separation of components. **Final harvest**: Four samples were collected from each fluxmeter cluster. Each comprised a whole-plant sample harvested from a 0.25 m^2 quadrat cut at ground level. The sample was separated into pea seeds and pod, leaf and stem residue components.
Potatoes	**Mid-season harvest**: One composite sample was collected from each fluxmeter cluster. Each comprised a whole-plant sample harvested from a 0.45 m^2 quadrat cut at ground level. There was no separation of components. **Final harvest**: Two composite samples were collected from each fluxmeter cluster. Each comprised a whole-plant sample harvested from a 0.25 m^2 quadrat cut at ground level. There was no separation of components.
Spinach	**Mid-season harvest**: One composite sample was collected from each fluxmeter cluster. Each comprised a whole-plant sample harvested from a 0.45 m^2 quadrat cut at ground level. There was no separation of components. **Final harvest**: Two composite samples were collected from each fluxmeter cluster. Each comprised a whole-plant sample harvested from a 0.25 m^2 quadrat cut at ground level. There was no separation of components.
Sweetcorn	**Mid-season harvest**: Four samples were collected from each fluxmeter cluster. Each comprised a whole-plant sample harvested from a 3.04 m^2 quadrat (2 m x 2 rows) cut at ground level. There was no separation of components. **Final harvest**: Four samples were collected from each fluxmeter cluster. Each comprised a whole-plant sample harvested from a 3.04 m^2 quadrat (2 m x 2 rows) cut at ground level. The sample was separated into cob and stover components.
Process tomatoes	**Mid-season harvest**: Four samples were collected from each fluxmeter cluster. Each comprised of three individual plants harvested from a 1.0 m^2 quadrat (0.5 m x 1 bed) cut at ground level. There was no separation of components. **Final harvest**: Four samples were collected from each fluxmeter cluster. Each comprised of three individual plants harvested from a 1.0 m^2 quadrat (0.5 m x 1 bed) cut at ground level. The sample was separated into tomato and residue components.
Ryegrass (seed)	**Mid-season harvest**: Four samples were collected from each fluxmeter cluster. Each comprised a whole-plant sample harvested from a 0.52 m^2 quadrat cut at ground level. There was no separation of seed and residue components. **Final harvest**: Four samples were collected from each fluxmeter cluster. Each comprised a whole-plant sample harvested from a 0.52 m^2 quadrat cut at ground level. There was no separation of seed and residue components.
Wheat	**Mid-season harvest**: Four samples were collected from each fluxmeter cluster. Each comprised a whole-plant sample harvested from a 0.25 m^2 quadrat cut at ground level. There was no separation of seed and residue components. **Final harvest**: Four samples were collected from each fluxmeter cluster. Each comprised a whole-plant sample harvested from a 0.25 m^2 quadrat cut at ground level. The sample was separated into grain and straw components.

APPENDIX 2. LOCATION OF NIWA CLIMATE STATIONS USED TO COLLECT WEATHER DATA AND DISTANCE OF THESE STATIONS FROM EACH SITE.

Site	Temperature	Solar radiation	Rainfall	Vapour pressure	Wind run	MSL pressure
Site 1 – Canterbury	Methven Three Springs, 1 km	Methven Three Springs, 1 km	Methven Three Springs, 1 km	Winchmore, 20 km	Methven Three Springs, 1 km	Methven Three Springs, 1 km
Site 2 – Canterbury	Methven, 13 km	Methven, 13 km	Methven, 13 km	Winchmore, 16 km	Methven, 13 km	Methven, 13 km
Site 3 – Canterbury	Chertsey, 23 km	Lincoln, 29 km	Ashburton, 36 km	Lincoln, 29 km	Chertsey, 23 km	Methven, 52 km
Site 4 – Manawatu	Levin, 2 km	Levin, 2 km	Levin, 2 km	Levin, 2 km	Levin, 2 km	Levin, 2 km
Site 5 – Manawatu	Palmerston North, 33 km	Palmerston North, 33 km	Bulls, 5 km	Palmerston North, 33 km	Palmerston North, 33 km	Levin, 46 km
Site 6 – Manawatu	Ohakune, 9 km	Mt Ruapehu, Chateau, 23 km	Ohakune, 9 km	Mt Ruapehu, Chateau, 23 km	Mt Ruapehu, Chateau, 23 km	Ohakune, 9 km
Site 7 – Hawke's Bay	Waipawa, 8 km	Waipawa, 8 km	Te Aute, 1 km[1]	Waipawa, 8 km	Waipawa, 8 km	Waipawa, 8 km
Site 8 – Hawke's Bay	Whakatu, 10 km	Whakatu, 10 km	Longlands, 1 km[2]	Whakatu, 10 km	Whakatu, 10 km	Whakatu, 10 km
Site 9 – Hawke's Bay	Takapau, 7 km	Dannevirke, 30 km	Takapau, 7 km	Takapau, 7 km	Takapau, 7 km	Takapau, 7 km
Site 10 – Matamata/Pukekohe	Matamata, 7 km	Toenepi, 22 km	Matamata, 7 km	Matamata, 7 km	Toenepi, 22 km	Matamata, 7 km
Site 11 – Matamata/Pukekohe	Pukekohe, 2 km	Pukekohe, 2 km	Pukekohe, 2 km	Pukekohe, 2 km	Pukekohe, 2 km	Auckland Aero, 25 km
Site 12 – Matamata/Pukekohe	Pukekohe, 19 km	Pukekohe, 19 km	Pukekohe, 19 km	Pukekohe, 19 km	Pukekohe, 19 km	Auckland Aero, 41 km

[1]Hawkes Bay regional council climate station. [2]Hortplus climate station.

The MPI SFF root zone reality project (401484) and the HortNZ northern fluxmeters project (HortNZ RI 1009) – summary of year 1 and year 2 activity. January 2017. PFR SPTS No.14210. This report is confidential to Foundation for Arable Research (ref X14-08); Horticulture New Zealand; Environment Canterbury; Horizons Regional Council; Hawke's Bay Regional Council; Environment Waikato; Auckland Regional Council; Ravensdown Cooperative Ltd.

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