Abhiram. G, Murray. M, Grafton. M, Jeyakumar. P, Bishop. P and Davies. C. E., 2019. Assessment of nitrogen fertilizers under controlled environment – A lysimeter design. In: *Nutrient loss mitigations for compliance in agriculture*. (Eds L.D. Currie and C.L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 32. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 8 pages.

ASSESSMENT OF NITROGEN FERTILIZERS UNDER CONTROLLED ENVIRONMENT – A LYSIMETER DESIGN

Gunaratnam Abhiram[1, 2], Murray McCurdy[3], Miles Grafton[1], Paramsothy Jeyakumar[1], Peter Bishop[1] and Clive E. Davies[4]

[1]School of Agriculture & Environment, Massey University
Private Bag 11 222, Palmerston North 4442, New Zealand.
[2]Department of Export Agriculture, Faculty of Animal Science and Export Agriculture
Uva Wellassa University, Badulla, Sri Lanka.
[3]CRL Energy, Lower Hutt, New Zealand.
[4]School of Food and Advanced Technology, Massey University, New Zealand.
Email: A.Gunaratnam@massey.ac.nz

Abstract

This paper introduces a closed system lysimeter design to measure fertilizer performance on ryegrass. The lysimeter will measure plant mass growth, gas emissions and leachate in a controlled climate environment based on a long term 90 day spring climate from the Taranaki. A range of commercial fertilizers will be compared to bespoke fertilizers manufactured under this project. This work, although undertaken in laboratory conditions will help quantify the impacts of nitrogenous fertilizers on the environment by mimicking actual conditions in a controlled setting. The study should provide data on the effectiveness of novel fertilizers manufactured within the programme; and other slow and controlled fertilizers, in reducing nitrogen leaching and greenhouse gas (GHG) emissions on pasture. Nitrogenous fertilizers readily leach as nitrates are highly soluble and GHG are emitted through volatilisation of ammonia and nitrous oxide. Reduced leaching and volatilisation increases fertilizer efficiency as less is wasted and more is attenuated in the plant. The aims of the research are to increase the effectiveness and efficiency of nitrogen fertilizer use in New Zealand. This should benefit farmers by reducing the amount of fertilizer applied, ideally reducing fertilizer cost, or at no extra cost by improved plant attenuation. This would also have an environmental benefit through reduced leaching and GHG emissions.

Key words: Controlled environment, greenhouse gas emission, leachate, lysimeter, nitrogen fertilizer.

Introduction

This paper introduces an advanced lysimeter design which will be used to measure the efficacy of fertilizers under controlled conditions. The growth of rye grass, gas emissions and leachate will be measured over a 90-day period using eight lysimeters with five replicates (40 in total).

The breakdown of fertilizers results in nitrogen losses, these losses are accentuated in intensive agricultural systems. The greenhouse gas emissions and leachate from these losses have a negative effect on; the hydrosphere, lithosphere and atmosphere in many ways. The losses take place through different steps of the nitrogen cycle as shown in figure 1. Since all these steps are an essential part of the natural cycle, loss of nitrogen cannot be avoided. However, better understanding of this cycle and factors affecting this cycle will possibly help to minimize the nitrogen losses through changing farming practices.

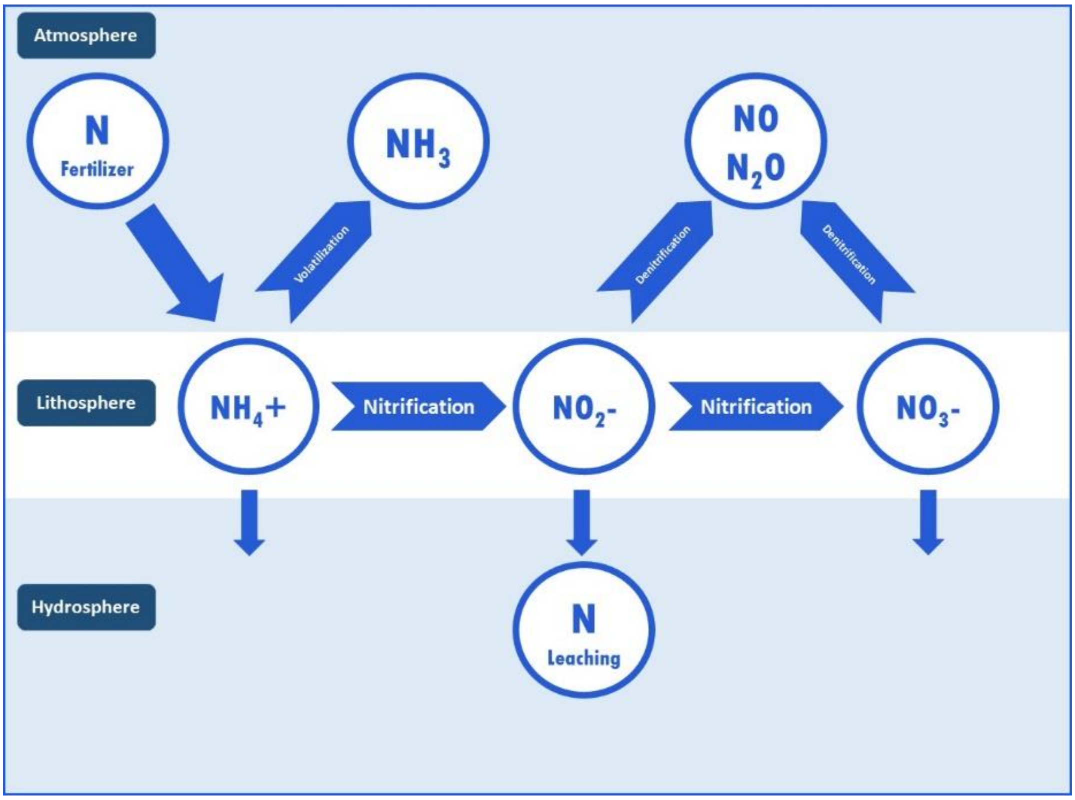

Figure 1. The primary ways of nitrogen loss in a nitrogen cycle.

Gaseous loss of N by means of nitrous oxide (N_2O) and nitric oxide (NO) takes place predominantly from the nitrite and nitrate ions under anaerobic conditions which favour the denitrification process especially in water-logged soils. The prevailing soil conditions have a great influence on how much N_2O is released to the atmosphere or reduced and released as harmless N_2 (Hahn and Junge, 1977). The other greenhouse gas emitted from nitrogen fertilizers is ammonia which releases as a result of the volatilization process which occurs more rapidly in warm conditions. In situations such as high rainfall events, where highly soluble nitrate and nitrite ions which are generated rapidly are available in supply greater than plants can uptake them, results in leaching loss to water bodies and ground water.

The contamination of soil and ground water aquifers with nitrates (NO_3^-), nitrites (NO_2^-) and other chemicals has been studied using different techniques such as soil core sampling, water sampling and lysimeters. Lysimeters are widely used by research scientists because they allow real time monitoring of water and solute movements more efficiently than other methods (Tan, 2005). A number of different lysimeters have been used to match the specific requirement of the research. However, all of the designs have their pros and cons. The evolution of lysimeter design has been taking place continuously to overcome the shortcoming of existing designs and to improve the accuracy of the results. The lysimeter design selection should match the research objectives and has a great influence on the accuracy of the outcome. In this research study a new modified design of a lysimeter which controls the environmental variables and can emulate real field conditions is proposed.

Materials and Methods

The lysimeter design

The use of lysimeters to assess nitrogen fertilizers under laboratory conditions will minimize the variability between treatments when compared to field studies. Therefore, a lysimeter design which closely emulates a field condition is critical. The lysimeter design proposed is to study the efficacy of nitrogen fertilizers under controlled conditions which imitate a specific field condition as closely as possible.

The novelty of the design is in the addition of a cap on top of a lysimeter to control the environmental variables with automatic control units. The lysimeter has a total length of 45 cm (40 cm under and 5 cm above the soil surface) with a diameter of 20 cm as shown in the figure 2. The cylindrical body of the lysimeter is made of PVC with wall thickness of 2.77 cm. The top and bottom flanges are made of 30 x 30 cm PVC plates which are glued and plastic welded to the body. A cone plate made of PVC with 0.3 gradient to direct the leachate towards the drainage pipe attached to it as shown in Figure 3(a). The PVC material was selected to minimize the heat conduction through the sidewalls which could lead to artefacts in the evapotranspiration calculation (Howell et al., 1991).

The bottom boundary of the soil matrix is attached to the fiberglass wick that drains the micropores and macropores flux. The top 10 cm of the fiberglass wick is frayed and spread radially on the cone plate and a fiberglass cloth is placed on top of the frayed wick to stop the soil leaching out and to increase the contact area between soil and wick as shown in Figure 3(b). The rest of the 20 cm wick is directed through the drainage tube functioning as a hanging water column (providing tension). Pre-treated fiberglass cloth and wicks (heated at 400 °C for 4 hours) are used in the lysimeter as described by Knutson et al., (1993). The bottom flange and cone plate are sealed with a rubber seal and tightly screwed to prevent the leachate leaking through.

The top flange of the lysimeter is connected to the cap using nuts and bolts. The cap is also made of PVC and has the same diameter as the lysimeter body. The 30 cm headspace functions as the atmosphere for the ryegrass and provide space for growth. The overhead single-central-COB-LED light with 1000 μmol m^{-2} s^{-1} is used as an artificial lighting source to ensure the uniformity of light for all experimental units. The voltage of the LED light is regulated through programing to provide the similar photosynthetically active radiation (PAR) as illustrated in Figure 5. Further, environmental variables such as temperature and relative humidity (RH) in the headspace are monitored by DHT22 sensors.

The rainfall events are generated with radial drippers connected to the top surface of the cap. These drippers automatically controlled through programming software and will simulate the rainfall regime shown in Figure 5. The temperature in the headspace is controlled by two means using air flow and a heatsink of LED-COB. The part of the heat generated by the LED light source is dissipated through a heatsink attached to it, the remaining heat is removed through the natural air circulation facilitated by the vents in the cap as shown in Figure 2. These vents are used for the collection of GHG, and they will be closed during the gas collection.

The soil temperature influences physiochemical and biological soil properties (Waring and Schlesinger, 1985). As these experiments are conducted in laboratory conditions, the natural soil temperature gradient of the Taranaki region has to be emulated using the cooling system. This is achieved by sending water through the cooling coil that is fixed to the outer surface of the lysimeter for bottom 20 cm as shown in Figure 2. In addition, monitoring the soil temperature is necessary to calculate the required cooling rate. Therefore, soil moisture sensors

(EC-5, Deccan devices) and temperature sensors (LM35 DZ) are placed at three soil depths as shown in Figure 2. The soil moisture sensors provide the volumetric water content of the soil at the relevant depths which is useful in modelling.

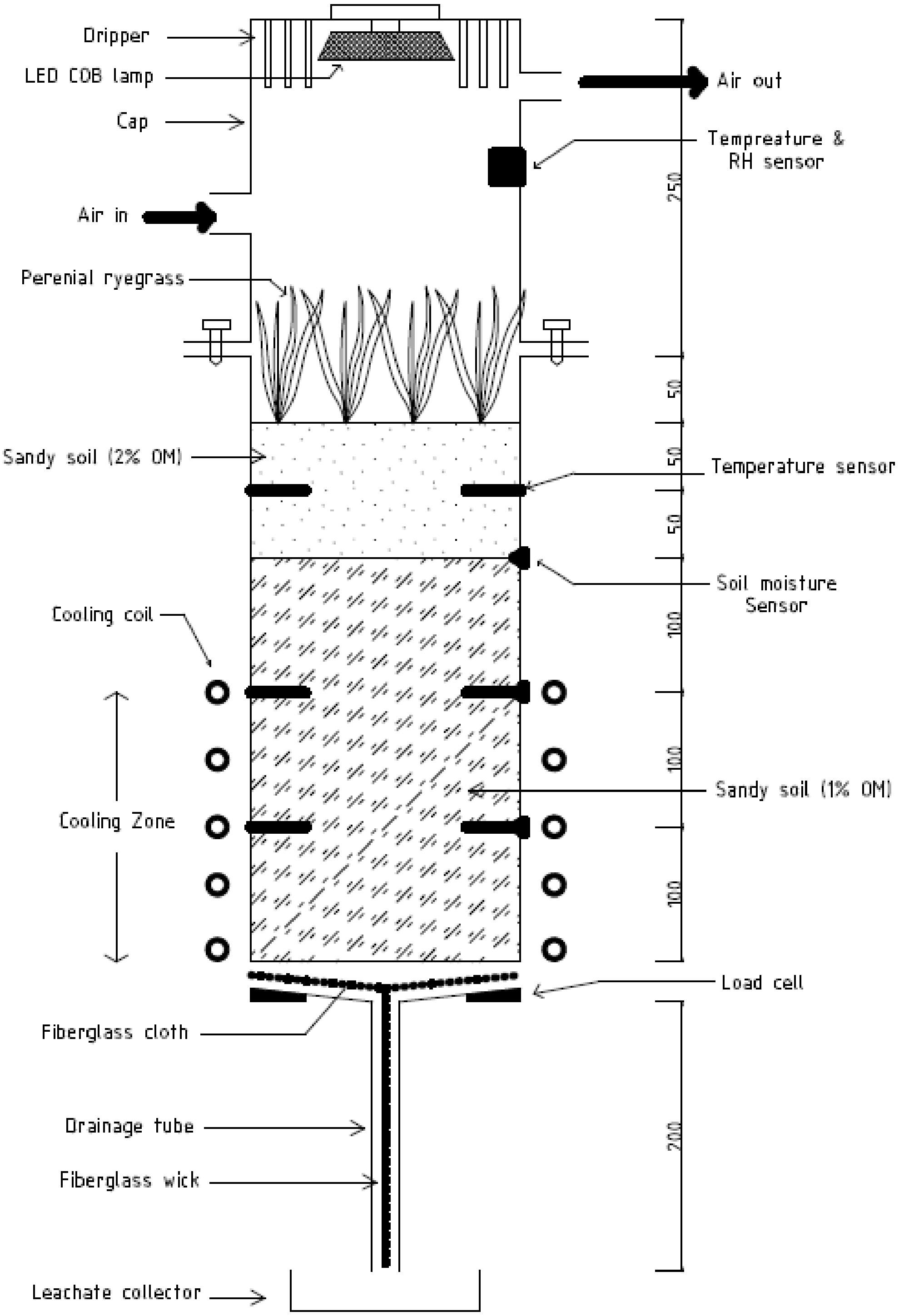

Figure 2. The schematic diagram of the lysimeter design.

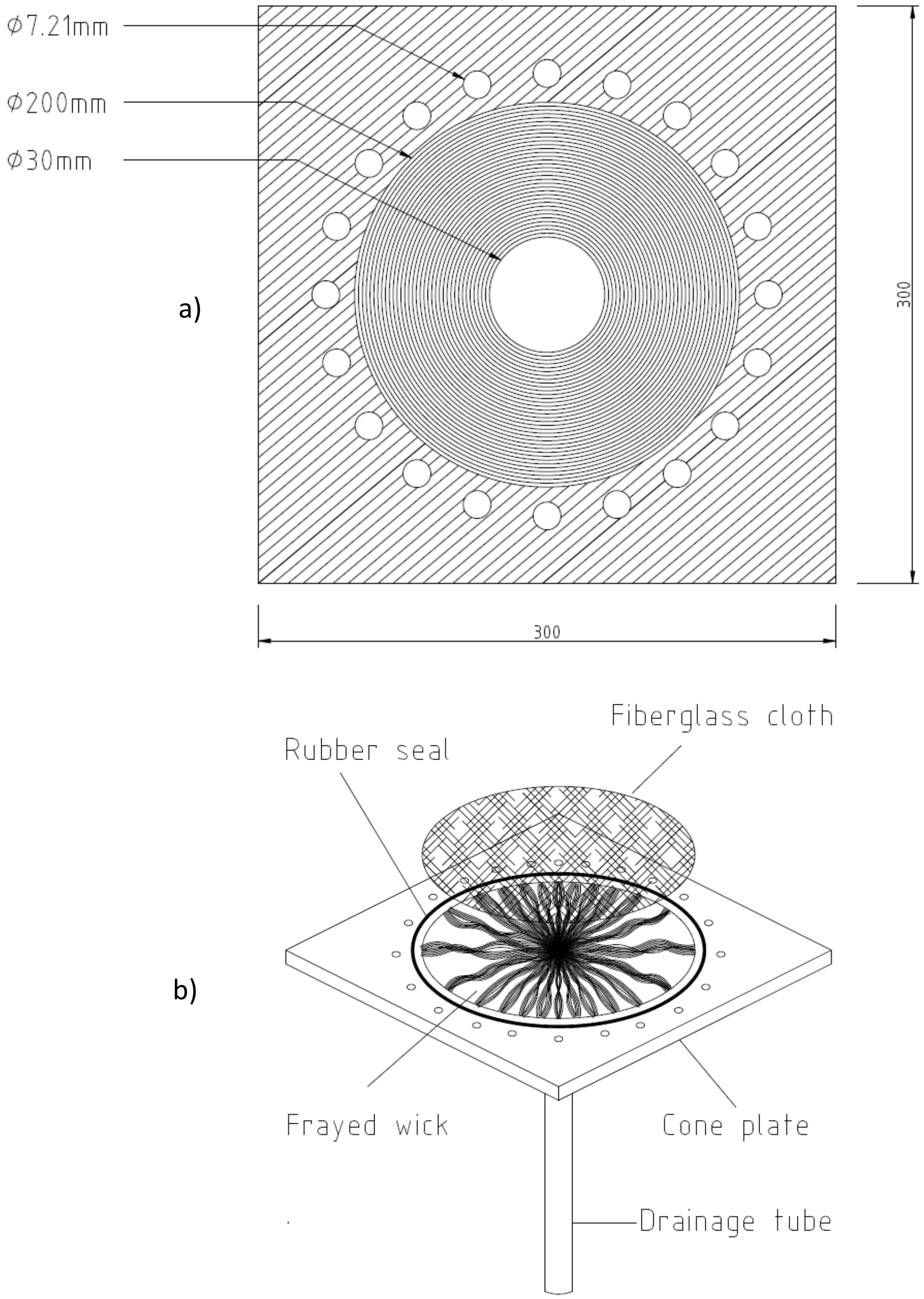

Figure 3. (a) The cone plate and (b) frayed fiberglass wick and cloth on the cone plate.

The lysimeters are supported with a triangular frame made of steel and one vertex of the triangular frame is fixed to a load cell. The weight changes during the experiment are measured by the load cell. This data will be used to calculate the evapotranspiration loss and any input and output changes that take place in terms of mass.

Soil matrix selection and packing

To ‘sensitise’ the lysimeters to remove nutrients via leaching, the majority of the soil matrix is composed of sand (with 2% organic matter at the top 10 cm height and rest with 1% organic matter). The sand has a relatively low surface area and relatively low quantities of alumino-silicates and organic matter for the adsorption of nutrient cations. The larger pore sizes in a matrix of this nature also allows more rapid movement of water down through the lysimeter profile.

The depth of the sand matrix (including the top 2% organic layer) is 40 cm. This allows 30 cm for the establishment of a mature root zone for ryegrass (and will serve as the plant uptake zone for nutrients released by the applied fertilisers). The additional 10 cm will serve as a matrix buffer below the root zone.

Uniform soil bulk density within and in between the lysimeters are critical to provide uniform pore volume to minimize the variance between experimental units. The bulk density of the soil column is maintained as 1.6 kgm^{-3} by careful packing through the following steps. The total length of the soil matrix is divided in to 10 cm segments and every segment is packed separately. The weight of the sand required for every segment is calculated using the volume and bulk density values. The calculated weight of sand is measured and packed into the lysimeter. A gentle force is applied to the sand to bring the level down to 10 cm mark, and the procedure is repeated for every segment of the soil matrix in the lysimeter.

The Climate Regime

A desired outcome of the lysimeter experiments is to have them operate under a climate regime that resembles field conditions as closely as possible. To enhance the experiments the lysimeter sand matrix is subjected to a significant number of pore volume flushes during the three-month lysimeter trial. The purpose accelerate the process of leaching (in this case water flux through the profile), thereby releasing nutrients from the applied fertiliser and their loss from the root zone via drainage. Under a less intensive leaching regime, it is probable that released nutrients (if any) will be more likely to be captured by the plant root zone or will not have leached during the experimental period.

The Taranaki region is well known for its high annual rainfall patterns and productive dairying systems. As such, it serves as an ideal climatic zone within which to interrogate NIWA’s climate database for suitable climate data stations with a complete and comprehensive range of climatic variables. A climate station named Stratford EWS (Agent No. 23872, Lat. -39.33726°, Long. 174.30487°, Elev. 300 m) in Taranaki region is selected for this study.

The selected rainfall regime used is from 2013 as it is a typical year for the general rainfall pattern of Stratford. The 2013 monthly rainfall totals lie within the 10-year mean (with the exception of rainfall deviation in July) (Figure 4). The months of Sep-Dec generally appear to satisfy this requirement, with September and November values lying on the +1standard deviation border.

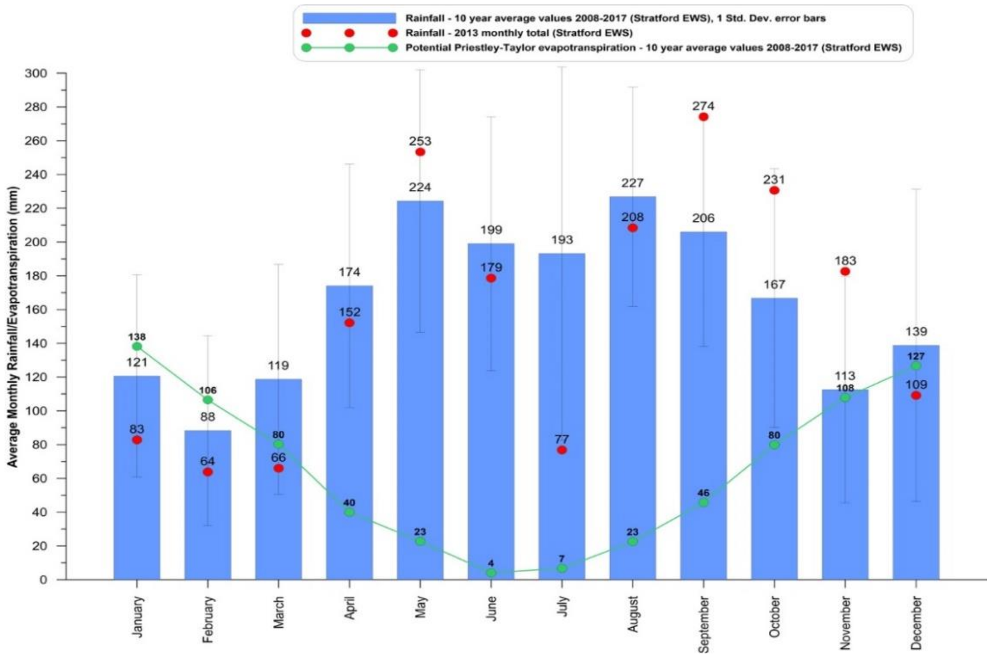

Figure 4. Ten-year (2008-2017) monthly average rainfall (mm) and potential evapotranspiration (mm) values from NIWA's Stratford EWS meteorological station. NIWA (2018)

During the three months period, 43 small and 5 big rainfall events are artificially created to emulate the September, October and November rainfall pattern as shown in Figure 5. Rainfall above 40 mm is taken as a large-rainfall event and anything below that has considered as small-rainfall event.

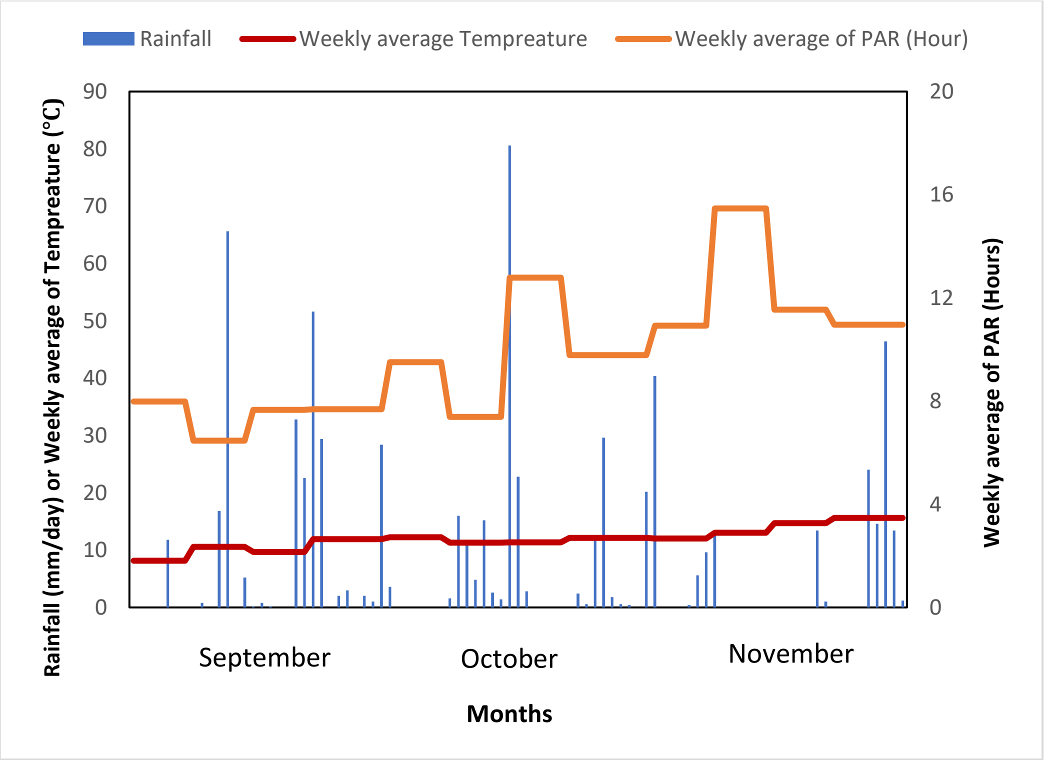

Figure 5: The climate regime during three months experimental period.

The data from the Stratford weather station is used to calculate the weekly-average-air temperature and photosynthatically active radiation (PAR) during the period of September to November, 2013 which are used for the climate regime (Figure 4). This weekly average air temperature will be maintained in the immediate environment of the grass using the temperature control. The COB-LED will be operated according to the average PAR hours to provide sufficient light for the photosynthesis of the grass.

Summary

We propose a modified and reproducible lysimeter design to assess and compare the efficacy of nitrogen fertilizers under controlled environmental conditions. The lysimeter design with automatic control units control the environmental variables. This manuscript comprehensively discusses the design parameters of the lysimeter, and a specific experimental procedure to measure ryegrass dry matter production, GHG emission and nitrogen leachate in a controlled climate environment based on a spring climate from the Taranaki region.

Future work

The efficiency of each fertilizer treatment will be assessed by measuring; ryegrass dry matter yield, greenhouse gas emissions and leachate loss. Leachates will be collected after every large rainfall event and will be analysed for NO_3^--N, NH_4^-N, Olsen P, dissolved organic carbon (DOC), cations, Al/Fe/Mn and pH. Based on the leachate analysis plant nutrients will be topped-up. The grown grass will be clipped at 5cm height from ground every month of the three months of the trial period and will be analysed for dry matter content, protein, total-N and Olsen P. The soil column will be sliced at every 5cm height and analysed for root weight and density of the grass and residual fertilizer. The greenhouse gas emission will be measured after the application of fertilizer treatments.

Acknowledgement

This research is supported by the Ministry of Business, Innovation and Employment (MBIE) Smart Ideas Grant. The Authors are grateful for this support. They also thank Dr. Mike Bretherton for his valuable support in selection of the climate regime for this study.

References

Hahn, J., & Junge, C. (1977). Atmospheric nitrous oxide: A critical review. Zeitschrift fuer Naturforschung A, 32(2), 190-214.

Knutson, J. H., Lee, S. B., Zhang, W. Q., & Selker, J. S. (1993). Fiberglass wick preparation for use in passive capillary wick soil pore-water samplers. Soil Science Society of America Journal, 57(6), 1474-1476.

Waring, R. H., & Schlesinger, W. H. (1985). Forest ecosystems. Analysis at multiples scales, 55.

Tan, K. H. (2005). Soil sampling, preparation, and analysis. CRC press.

NIWA (2018). Climate data for Taranaki - NIWA’s Stratford EWS meteorological station. Retrieved on 14th August 2018 from https://cliflo.niwa.co.nz/

Howell, T. A., Schneider, A. D., & Jensen, M. E. (1991). History of lysimeter design and use for evapotranspiration measurements. In Lysimeters for evapotranspiration and environmental measurements (pp. 1-9). ASCE.