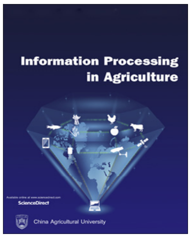
Available at www.sciencedirect.com

INFORMATION PROCESSING IN AGRICULTURE 6 (2019) 279–284

journal homepage: www.elsevier.com/locate/inpa



Micro-sonic sensor technology enables enhanced grass height measurement by a Rising Plate Meter

D. McSweeney [a,b,*], N.E. Coughlan [c], R.N. Cuthbert [c], P. Halton [d], S. Ivanov [b]

[a] *Teagasc, Animal & Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland*
[b] *Telecommunications Software & Systems Group, Waterford Institute of Technology, Waterford, Ireland*
[c] *Institute for Global Food Security, School of Biological Sciences, Queen's University Belfast, Medical Biology Centre, 97 Lisburn Road, Belfast BT9 7BL, Northern Ireland, United Kingdom*
[d] *True North Technologies, Unit 14, Shannon Business Centre, Shannon, County Clare, Ireland*

ARTICLE INFO

Article history:
Received 16 June 2018
Received in revised form
11 August 2018
Accepted 16 August 2018
Available online 7 December 2018

Keywords:
Decision support systems
Dry matter yield
Grassland
Rising plate meter
Precision agriculture
Wireless sensor network

ABSTRACT

Globally, the Rising Plate Meter (RPM) is a device used to measure compressed sward height, to enable estimation of herbage mass. Despite improved farm management practices aided by a variety of technological advances, the standard design of a RPM has remained relatively unchanged. Recently, however, a RPM utilising a micro-sonic sensor, with digital data capture capability *via* a Bluetooth communications link to a smart device application, has been developed. Here, we assess the comparable ability of both a standard cumulative ratchet counter RPM and the micro-sonic sensor RPM, to accurately and precisely measure fixed heights. Moreover, as correct allocation of grazing area requires accurate geolocation positioning, we assess the associated GPS technology. The micro-sonic sensor RPM was significantly more accurate for height capture than the cumulative ratchet counter RPM. Overall, across all heights, the cumulative ratchet counter RPM underestimated height by 7.68 ± 0.06 mm (mean ± SE). Alternatively, the micro-sonic sensor RPM overestimated height by 0.18 ± 0.08 mm. In relation to a practical applications, these discrepancies can result in an under- and overestimation of dry matter yield by 13.71% and 0.32% kilograms per hectare, respectively. The performance of the on-board GPS did not significantly differ from that of a tertiary device. Overall, the wireless technology, integrated mapping, and decision support tools offered by the innovative micro-sonic sensor RPM provides for a highly efficacious grassland management tool.

1. Introduction

The development of electronic and data transmission systems continues to enable radical changes in agricultural practices worldwide [1]. Enhanced data capture, information and communication technologies have facilitated considerable improvements to the efficiency, effectiveness and productivity of various agricultural sectors [1,2]. However, these technologies remain substantially underutilised in modern

---

[*] Corresponding author at: Teagasc, Animal & Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland.
E-mail address: diarmuidmcsweeney90@gmail.com (D. McSweeney).

Peer review under responsibility of China Agricultural University.
https://doi.org/10.1016/j.inpa.2018.08.009

agricultural production systems [3]. Although smart farming systems may utilise these technological advancements to feed into automated management systems, incorporation of information and communication technologies into machinery, equipment, and sensors can also facilitate real-time decision support tools within non-automated systems.

The profitability of intensive pasture-based systems is reliant upon precise, accurate and timely grazing management strategies. Consequently, the implementation of precision data capture and communication technologies in relation to grassland management represents a considerable opportunity to enhance farm productivity and profitability [2,4,5]. Sward herbage mass (HM) can be utilised to inform efficient daily grassland management, *via* allocation of a sufficient grazing area to meet (but not exceed) the daily nutritional demands of grazing animals [6,7]. Moreover, regular estimation of paddock HM can be utilised to inform long term grassland management, to achieve optimal pasture utilisation and animal performance [6]. Currently, in Ireland, for example, farmers' use of grass measurement remains low; only *circa* 10% of dairy farmers conduct weekly grass measurements. Therefore, there exists considerable potential to increase grass measurement frequency and farmland productivity [5,8].

Traditionally, HM is determined by observer visual estimation. However, this method is highly subjective and prone to considerable inter-observer variability [9]. Although more accurate estimates of HM can be obtained from the sward weights obtained from clipped sample quadrats, this process is destructive and time intensive [10,11]. The Rising Plate Meter (RPM) is a grassland management tool utilised worldwide as a method of measuring compressed sward height (CSH). This technology is considered to be an accurate, precise, time efficient, and less labour intensive method for sampling HM [12,13], from which dry matter yield (DMY; i.e. the grass nutritional value) can be calculated. However, device accuracy can be affected by numerous factors, such as growth state of plants [14], season [15], species composition [16] and grassland management regime [17].

Despite many recent advances in various precision agriculture, data capture and communication technologies [3,1], the design and application process of RPMs has remained similar to that of earlier devices [12,16]. Most RPMs consist of an aluminium steel plate through which a one metre vertical shaft freely passes. When this shaft is lowered to ground level within a grass sward, the plate will rise (depending on grass height) relative to the shaft, and this distance is recorded on a cumulative ratchet counter mounted upon the device. The average CSH can then be calculated across multiple samples. The RPM is calibrated by relating the CSH readings of a number of sample quadrats to the DMY of these quadrats, cut to ground level.

In recent years, technological advances such as various plant sensitive sensors, Global Positioning Systems (GPS), Bluetooth connectivity, and low-power portable user interfaces (smart phones and tablets), have been used to improve farm management practices [1,3,5]. These data capture and communication technologies can likely be utilised to improve grass measurement and facilitate real-time decision support

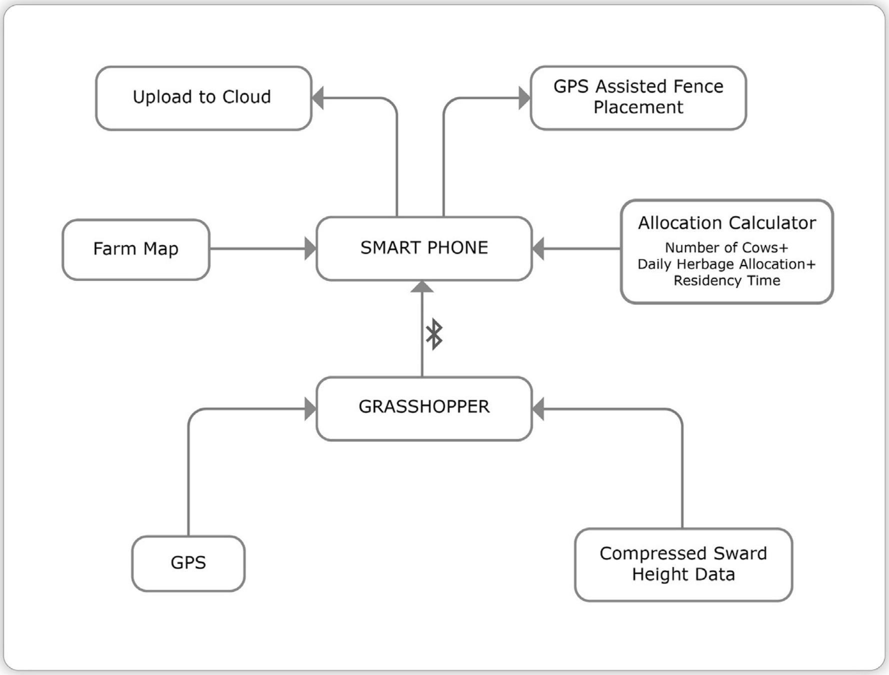


Fig. 1 – Infographic depicting the wireless communication process between the Grasshopper micro-sonic sensor Rising Plate Metre, global positioning system, and accompanying smart device application: (1) GPS and compressed sward height data are captured by the device; (2) this data is wirelessly transmitted to the associated smart device application; (3) a designated farm paddock area can be created, stored, or selected; (4) grazing intensity parameters can be inputted; (4) the Allocation Calculator can provide real-time decision support; (5) GPS assisted fence placement is provided; and (6), all data is consolidated within the smart device application, and can be wirelessly uploaded to Cloud computing and integrated smart farm databases.

in relation to grassland management, e.g. grazing allocations. Recently, a RPM utilising a micro-sonic sensor and digital data capture *via* a Bluetooth communications link to a smart device application has been developed (Fig. 1).

In essence, the time of flight- taken from transmission of a micro-sonic beam to return of the reflected echo signal is used to calculate the distance between the sensor and the sampling plate. The higher the upwards displacement of the sampling plate, the shorter the time between transmission and return of the reflected signal. The height of the object underneath the rising plate is then calculated. This measured height is then transmitted *via* Bluetooth to a smart device. This smart device also utilises GPS technology for paddock mapping and advisory (decision-support) grazing-area allocation based on animal in-take requirements. Although the cumulative ratchet counter RPM does not facilitate on-board GPS, users can use tertiary GPS enabled devices to manually map paddock areas.

Here we assess the accuracy and precision of RPM height measurements by both the standard cumulative ratchet counter, and the newly developed micro-sonic sensor unit. Given that correct allocation of grazing area requires accurate geolocation positioning, the on-board GPS technology of the newly developed RPM was compared to the GPS functionality of a representative and commonly used device, i.e. a smartphone.

2. Methods

2.1. *Experiment 1: Repeated accuracy of height data capture by two Rising Plate Meters (RPMs)*

A cumulative ratchet counter RPM (Jenquip; Filip's Manual Folding Plate Meter, New Zealand) and the micro-sonic sensor RPM (Grasshopper II; True North Technologies, Ireland) were used to measure standing PVC pipes (110 mm diameter; $n = 31$) of known heights, 25–178 mm [18]. The pipes were accurately cut to the specified length by a professional engineering company. All pipe sections were placed on a level surface, and each pipe was randomly chosen to be measured by the RPMs. A total of 30 height measures were recorded per pipe by each RPMs. The micro-sonic sensor RPM sample measurements were obtained first, immediately followed by the cumulative ratchet counter RPM.

Although the micro-sonic sensor RPM facilitated instantaneous digital capture and storage (.csv format) of measurement data, via a Bluetooth communications link between the sensor unit and an accompanying smart device application (Android operating system), the ratchet counter RPM data was recorded by hand, and height measurement calculated. Prior to data capture, the micro-sonic sensor was normalised to ensure a baseline of height zero was established. The cumulative ratchet counter does not require normalisation.

2.2. *Experiment 2: Geolocation performance of a Rising Plate Meter (RPM) utilising on-board and external GPS technology*

To assess device geolocation performance, latitude and longitude output was sampled directly upon a known georectified point that consisted of a brass rivet set in concrete footpath (IRENET control station D130, Ordnance Survey Ireland). Both the on-board GPS and GPS functionality of a representative smartphone device (Samsung S7 Edge SM-G935F OS 7.0), were simultaneously assessed (both $n = 30$). The smartphone was held directly over the handle of the RPM, which was positioned centrally and precisely upon the georectified point. To force the devices to continually recalculate their geolocation positioning, between each georectified sampling event, the experimental operators walked (≥20 m) in a random direction away from the sampling point and recorded an additional non-test measurement with both devices. Although, mobile network accessibly may improve geolocation accuracy, in situ signal connection opportunities can vary greatly. Therefore, the smartphone mobile network connection was disabled during sampling. This required the smartphone to rely on satellite connections only when triangulating its geolocation, as does the RPM device.

2.3. *Statistical analysis*

All statistical analyses were performed using R v3.4.3 [19]. The difference between actual and recorded pipe heights was converted to proportional error and analysed using beta regression with the 'betareg' package in R [20]. This model incorporated both the effects of 'device' and 'pipe height', and their interaction. We transformed data to reduce extremes (0 s) prior to analysis [21]:

$$y_t = (y(n-1) + 0.5)/n \tag{1}$$

where y_t is the transformed output and n is the sample size.

As the captured geolocation data did not meet the assumptions of parametric tests, latitudinal and longitudinal error, relative to the georectified baseline point, were analysed between devices using paired Wilcoxon tests.

3. Results

Across all pipe heights, the cumulative ratchet counter RPM underestimated height (mean ± SE) by 7.68 ± 0.06 mm, with a maximum underestimate of 11 mm (Fig. 2A). Alternatively, the micro-sonic sensor RPM overestimated height by 0.18 ± 0.08 mm, with a maximum overestimate of 6 mm (Fig. 2B). Overall, the micro-sonic sensor RPM more accurately measured the pipe heights than the cumulative ratchet counter RPM ($z = 40.42$, $P < 0.001$; Fig. 2). Proportional recording errors were reduced significantly as pipe heights increased overall ($z = -9.08$, $P < 0.001$). The 'RPM × pipe height' effect was significant ($z = -16.60$, $P < 0.001$), reflecting greater differences in accuracy between the RPMs at lower pipe heights.

Neither of the devices differed significantly in their accuracy relative to a georectified point, across either latitudinal ($V = 346.00$, $P = 0.25$) or longitudinal readings ($V = 344.00$, $P = 0.26$. Both devices were consistently precise (Table 1).

4. Discussion

Accurate, precise and timely measurement of pasture HM is integral to effective implementation of optimal grazing management practices, particularly for farmers who rely on pasture as a primary feed source. This examination of a

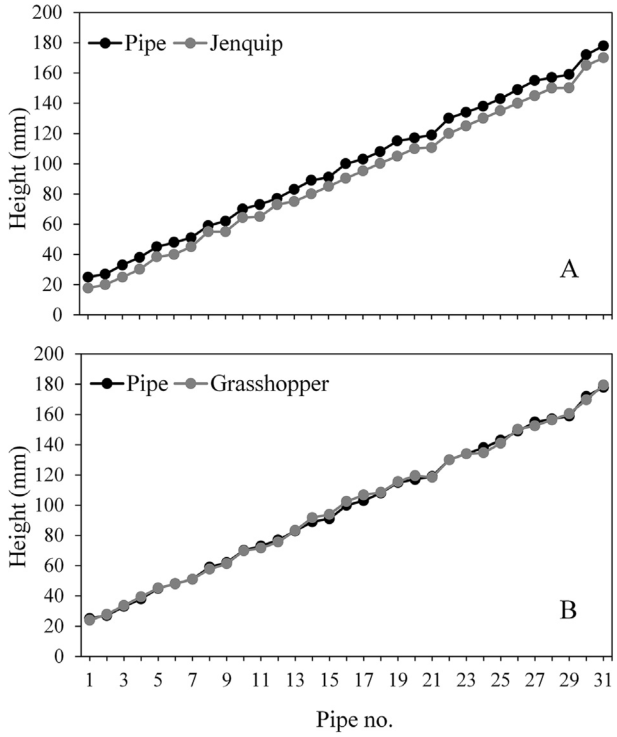


Fig. 2 – Comparable ability of the cumulative ratchet counter Rising Plate Metre (A: Jenquip), and micro-sonic sensor Rising Plate Metre (B: Grasshopper), to accurately measure fixed heights ($n = 31$). Standard error ≤ 1 in all cases.

recently developed micro-sonic sensor, has shown that such technological advancements can enhance the accuracy and precision of grass measurement and data capture. Until recently, the traditional cumulative ratchet counter design only facilitated measurement in increments of five millimetre (0, 5, 10 ...), however, the micro-sonic sensor RPM has accomplished one millimetre increments. Although the average underestimation of height by the cumulative ratchet counter RPM (7.68 ± 0.06 mm) is low, small errors in measurement can lead to larger errors over large pasture areas. At an average overestimate of 0.18 ± 0.08 mm, the micro-sonic sensor has been shown to be highly accurate.

As a brief practical example, in the case of the cumulative ratchet counter, if we assume height of 1 cm = 250 kg dry matter yield per hectare, then 250 kg × 0.768 cm = 192 kg of DMY. In a simplified gazing allocation regime of ten grazing assignments per year, an underestimation of 192 kg DMY ha^{-1} is multiplied by ten, giving an error of 1920 kg DMY ha^{-1}. Scaling upwards, across a 50 ha farm, annual underestimation is 50 × 1920 = 96,000 kg DMY ha^{-1}. If we assume the farm (50 ha) will grow 14,000 kg DMY ha^{-1}, then annual dry matter production is 700,000 kg ha^{-1}. The annual underestimation of DMY would be 13.71% (i.e. 960,000 ÷ 700,000). Contrastingly, inflation of grass height by 0.18 mm on the same hypothetical farm and grazing regime, results in an annual overestimated DMY of 0.32% when using the micro-sonic sensor RPM.

Underestimation of available DMY results in poor allocation of forage to animal requirements. In essence, the stocking rate could be increased to better utilise the available grassland and increase overall farm production and profitability. In Ireland, for example, one metric tonne of grass has a monetary feed resource value of €162–267 to dairy farmers [5,22], depending on milk market prices. Underestimation of available DMY essentially results in a loss of this forage value to the overall farm profitability.

The micro-sonic sensor RPM, by utilising on-board GPS technology, can facilitate digital data capture features not currently associated with other RPMs, which utilise a cumulative ratchet counter design. Use of the micro-sonic sensor RPM would enable the real-time paddock mapping, give fence plotting directions, and direct appropriate grass allocation for the herd. The integration of the smart device application would allow for real-time assessment of the palatability of grass swards by consideration of pre- and post-grazing residuals.

The micro-sonic senor RPM incorporates GPS technology to aid decision support of grazing area allocation in relation to animal in-take requirements and available sward HM. Although the cumulative ratchet counter RPM does not facilitate on-board GPS, basic GPS enabled smartphones can be used to map paddock areas within an integrated Geographic Information System (GIS) environment. However, while the GPS enabled RPM did not perform better than the smartphone, manual recording of GPS data and the associated cumulative ratchet scores is a time consuming process. Automatic capture of geolocation data by the micro-sonic sensor RPM, communicated through a Bluetooth communications link to a smart device application, and further presented in a single data file, represents a highly efficient method for real-time decision support. Further automated geo-tagging of ground reference points can facilitate calibration of herbage evaluation from satellite aerial imagery, and integrated with within a communication network for the transmission of data from other in field sensor technology.

The application of any grass height measurement technique requires the operator to collect a sample size within a pasture that is sufficient to ensure that the variation in grass height and HM is accurately captured. The smart device appli-

Table 1 – Mean latitude and longitude recorded by each device in relation to the known georectified sampling point (IRENET control station D130, Ordnance Survey Ireland).

Device	Mean latitude (±1SD)	Georectified latitude	Mean longitude (±1SD)	Georectified longitude
Grasshopper	52.16265970 (±5.145 × 10^{-5})	52.16264111	8.27727091 (±1.327 × 10^{-4})	8.27729278
Smartphone	52.16265204 (±6.827 × 10^{-5})	52.16264111	8.27726680 (±1.121 × 10^{-4})	8.27729278

cation associated with the micro-sonic sensor RPM, coupled with the available GPS technology, can facilitate assessment of intra paddock variations in grass growth and grazing pressure, while inter and intra paddock DMY can be mapped and assessed to inform future fertiliser applications. Captured data can subsequently be uploaded to on-line decision support tools, which can advise on the allocation of grazing areas. Although manual placement of fences is necessary at present, there is considerable potential to link the recommended grazing area allocation to fenceless farming (i.e. virtual fencing; [23]). Therefore, while the cumulative ratchet counter RPM has been a valuable tool for researchers and practitioners since its conception, the recently developed micro-sonic sensor RPM represent a significant advancement for grassland management. As the micro-sonic sensor device relies on algorithms to calculate DMY, rather than an operator performed manual calculation, the associated smart application can be directed to make formula corrections for seasonal and regional HM variation [24]. However, despite the substantial benefits, further research and development is required to improve application of this device (e.g. incorporation of grass quality measurement), and integrate the device into smart farming systems.

Conflict of interest

Paddy Halton is employed by True North Technologies Ltd., but this did not inappropriately influence the interpretation of the data or the reporting of the research results. True North Technologies Ltd. had no role in the collection, analyses, or interpretation of data, and in the decision to publish the results.

Acknowledgments

We thank Dr Luc Delaby, Dr Bernadette O'Brien and Prof Pat Dillion for helpful contributions to previous work on which this study is based. We gratefully thank Caitlyn Cuthbert for assistance with the preparation of this manuscript.

Author contributions

DMS and NEC preformed the experiment, RNC analysed the data. PH advised on experimental design. All authors contributed to the writing the manuscript.

Disclaimer

Mention of commercial products is solely for the purpose of providing specific information and should not be construed as a product endorsement by the authors or the institutions with which the authors are affiliated.

REFERENCES

[1] Pivoto D, Waquil PD, Talamini E, Finocchio CPS, Dalla Corte VF, de Vargas Mores G. Scientific development of smart farming technologies and their application in Brazil. Inform Process Agric 2018;5:21–32.
[2] Zhang Y, Chen D, Wang S, Tian L. A promising trend for field information collection: An air-ground multi-sensor monitoring system. Inform Process Agric 2018;5:224–33.
[3] O'Grady MJ, O'Hare GMP. Modelling the smart farm. Inform Process Agric 2017;4:179–87.
[4] Wathes CM, Kristensen HH, Aerts JM, Berckmans D. Is precision livestock farming an engineer's daydream or nightmare, an animal's friend or foe, and a farmer's panacea or pitfall? Comp Electron Agric 2008;64:2–10.
[5] Dillon P. The Irish dairy industry-Planning for 2020. In: National Dairy Conference '11, The Irish Dairy Industry: To 2015 and Beyond. Cork, Ireland; 2011. p. 1–24.
[6] Hanrahan L, Geoghegan A, O'Donovan M, Griffith V, Ruelle E, Wallace M, Shalloo L. PastureBase Ireland: A grassland decision support system and national database. Comp Electron Agric 2017;1:193–201.
[7] Kennedy E, McEvoy M, Murphy JP, O'Donovan M. Effect of restricted access time to pasture on dairy cow milk production, grazing behaviour, and dry matter intake. J Dairy Sci 2009;292:168–76.
[8] Creighton P, Kennedy E, Shalloo L, Boland TM, O' Donovan M. A survey analysis of grassland dairy farming in Ireland, investigating grassland management, technology adoption and sward renewal. Grass Forage Sci 2011;66:251–64.
[9] Tucker CJ. A critical review of remote sensing and other methods for non-destructive estimation of standing crop biomass. Grass Forage Sci 1980;35:177–82.
[10] Brummer JE, Nichols JT, Engel RK, Eskridge KM. Efficiency of different quadrat sizes and shapes for sampling standing crop. J Range Manage 1994;47:84–9.
[11] Adesogan AT, Givens DI, Owen E. Chemical composition and nutritive value of forages Chapter 11. In: T'Mannetje L, Jones RM, editors. Field and laboratory methods for grassland and animal production research. Wallingford UK: CABI Publishing; 2000. p. 263–78.
[12] Sanderson MA, Rotz AC, Fultz SW, Rayburn EB. Estimating forage mass with a commercial capacitance meter, rising plate meter, and pasture ruler. Agron J 2001;93:1281–6.
[13] Soder KJ, Sanderson MA, Stack JL, Muller LD. Intake and performance of lactating cows grazing diverse forage mixtures. J Dairy Sci 2006;89:2158–67.
[14] Mosquera-Losada R, Gonzalez-Rodriguez A. Effect of annual stocking rates in grass and maize + rye system on production by dairy cows. Grass Forage Sci 1998;53:95–108.
[15] Bransby DI, Matches AG, Krause GF. Disk meter for rapid estimation of herbage yield in grazing trials. Agron J 1977;69:393–6.
[16] Castle ME. A simple disc instrument for estimating herbage yield. Grass Forage Sci 1976;31:37–40.
[17] Powell TL. Evaluation of weighted disc meter for pasture yield estimation in intensively stocked dairy pasture. New Zeal J Exp Agric 1974;2:237–41.
[18] McSweeney D, Foley C, Halton P, O'Brien B. Calibration of an automated grass height measurement tool equipped with global positioning system to enhance the precision of grass measurement in pasture-based farming systems. In: Grassland Science in Europe '15, Grassland and forages in high output dairy farming systems. The Netherlands; 2015. p. 265–67.
[19] R Core Development Team. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2017.
[20] Cribari-Neto F, Zeileis A. Beta regression in R. J Stat Softw 2010;34:1–24.

[21] Smithson M, Verkuilen J. A Better Lemon Squeezer? Maximum-likelihood regression with beta-distributed dependent variables. Psychol Methods 2006;11:54–71.

[22] French P, Hanrahan L, Shalloo L. Principles of sustainable dairy expansion. In: Moorepark'15 Irish Dairying – Sustainable Expansion. Cork, Ireland; 2015. p. 9–14.

[23] Umstatter C. The evolution of virtual fences: A review. Comp Electron Agric 2011;75:10–22.

[24] Nakagami K. Effects of sites and years on the coefficients of rising plate meter calibration under varying coefficient models. Grassl Sci 2016;62:128–32.