AN INEXPENSIVE AND EFFECTIVE METHOD FOR SIMULATING CATTLE TREADING DAMAGE ON PASTURE

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Abstract

It may seem obvious to use livestock to study the effect of treading damage on pasture, however live animals limit the likelihood of achieving spatially uniform damage, and therefore are unsuitable for the study of treading damage in small plot experiments, or where studies necessitate the identical treading of replicate plants. In these situations, a mechanical device capable of generating repeatable and realistic treading damage is desirable. There have been multiple attempts at creating such a device, however these are typically manufactured at substantial cost and are often complicated and/or poorly maneuverable in the field. Thus, the challenge was to create a simple, low-cost, novel treading device that would provide a realistic simulation of cattle treading on pasture plants. The device created consisted of a wooden post laden with cast-iron weights with steel handles and foot pegs so that a single operator could shift the device into position before stepping onto it to generate the pug mark. The device was designed to produce a pressure equivalent to the hoof of a 520-560 kg cow. Due to its resemblance to a pogo stick, the device was aptly named the puggo-stick. In an experiment at Massey University's No.4 Dairy farm, the effects of treading damage at varying severities by the puggo-stick were assessed on plantain (*Plantago lanceolata* L.) and perennial ryegrass (*Lolium perenne* L.) dominant pastures. The treading severities imposed on each pasture type were facilitated by differences in soil moisture content at the time of treading and included heavy damage (high soil moisture), light damage (optimal soil moisture for grazing) and no treading. Measurements included pug mark depth and density, and the herbage regrowth of each pasture type following damage. The treading damage caused by the puggo-stick was comparable to damage caused by cattle in previous studies, with severity (pug depth) increasing with an increase in soil moisture content. The resulting reduction in the herbage accumulation of both pasture types following damage by the puggo-stick was comparable to the reduction in herbage growth observed by earlier researchers for pastures subjected to cattle treading damage. These results suggest that the puggo-stick generated treading damage comparable to that of live cattle, and so appears to be an inexpensive and effective method for simulating cattle treading damage in pastures and could be considered for use in future experiments.

Introduction

Treading damage by grazing livestock, and the subsequent decrease in the production of affected pastures are regarded as inevitable on most New Zealand pastoral farms in any given year (Howes 2019), and thus has been well researched. Treading damage typically occurs between late-autumn and early spring, when soil moisture content (SMC) is elevated due to increased rainfall and low evapotranspiration, and when livestock are managed in confined rotations. The extent to which a pasture is damaged during this period is largely governed by SMC, because at a high SMC, soil is generally susceptible to treading damage regardless of its texture or structure (Howes 2019). The treading damage caused by livestock is typically spatially random, and can result in a large variability of treading pressure (Di et al. 2001), both of which reflect the randomness of livestock movement and behavior within an allotted area of pasture. Thus, the use of grazing livestock for implementing treading damage in small-plot experiments, or in experiments that require uniform treading damage is impractical. In such experiments, a mechanical device capable of producing repeatable and life-like treading damage is desired.

There have been several attempts at manufacturing such a device, however they appear to have come at a high cost for investigators and/or have required proper technical aptitude (Di et al. 2001; Hu et al. 2018). Given that PhD researchers, such as the current author, are often lacking somewhat in one or both of these areas, and are usually confined by time limits, experiments often require a certain amount of ingenuity. On this occasion, that manifested in the development of a novel treading device. The current work provides a short review of previous treading devices and set out to create and assess an uncomplicated and low-cost alternative device. The evaluation of the newly created puggo-stick was based on its ability to produce pug depths similar to those of dairy cows and cause pasture damage similar to that documented in previous cattle treading studies.

Review of mechanical treading damage devices

The recording penetrometer

The recording penetrometer, devised by Scholefield and Hall (1986) was evaluated against force patterns obtained with the use of a Kistler multicomponent force-platform, which measured forces exerted on the ground by a 530kg walking dairy cow. With a hoof surface area of 100cm^2 the average vertical force imposed over one hoof step was 250kpa; the average vertical stress by a standing, stationary cow is 132.5kpa. This instrument was able to test the strength of soil, by directly measuring the displacement of the mechanical limb. The hoof prints produced by the machine were shallow compared with those produced by live cattle, however a reduction in soil treading resistance correlated well with an increase in SMC.

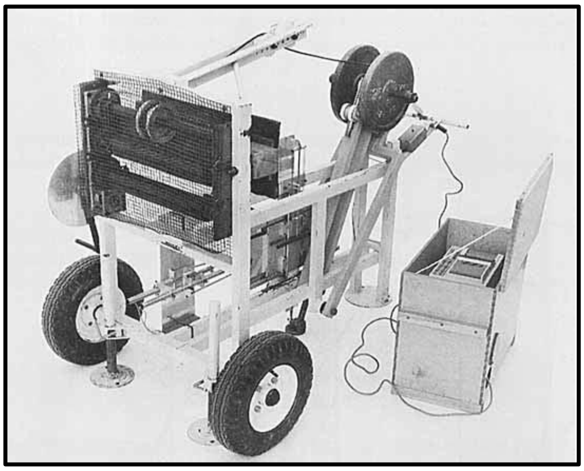

Photo 1: The recording penetrometer (Scholefield & Hall 1986).

Artificial pivot-hoof

The artificial hoof created by Abdel-Magid et al. (1987) was cast of bronze from the mould of a steel hoofprint. The surface area of the hoof was $85cm^2$. The hoof was suspended from a long, weighted metal handle, and when lowered onto the soil, delivered a static load of 118kpa. The instrument was able to influence the soil bulk density, water infiltration rates and shoot biomass of samples. This design was simple and effective for use on soil in pots or lysimeters, but would have limitations for field use, given its fixed position.

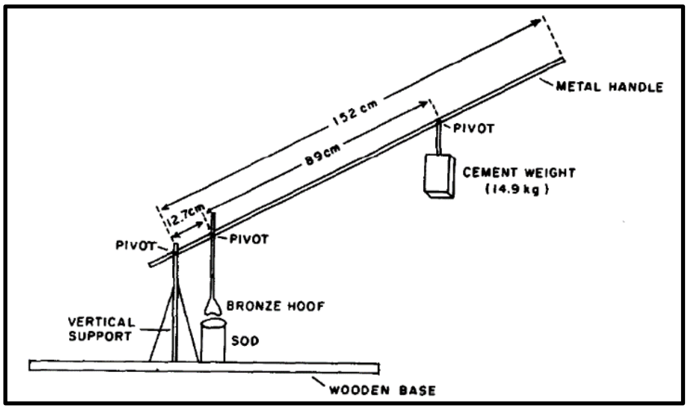

Photo 2: Schematic diagram of the artificial hoof apparatus (Abdel-Magid et al. 1987).

Mechanical hoof

The mechanical hoof devised by Di et al. (2001) comprised of an artificial hoof mounted onto a compressed air ram system on wheels. The steel hoof was modelled on an adult Friesian cow. The hoof was split into two halves, which were joined by a pivot in the middle, allowing some independent movement by each half, just as the halves of a cow's hoof. The surface area of the steel hoof was $90cm^2$ and delivered a pressure of 220kpa. Treading with the mechanical hoof on pasture caused increases in soil bulk density and reductions in soil microporosity and pasture DM yield. This design was efficient and closely replicated the vertical action of a cow's hoof, providing an excellent simulation of cattle treading to small plots and lysimeters. However, given the total weight of the device was 450kg, it was probably difficult to transport and physically difficult to manoeuvre.

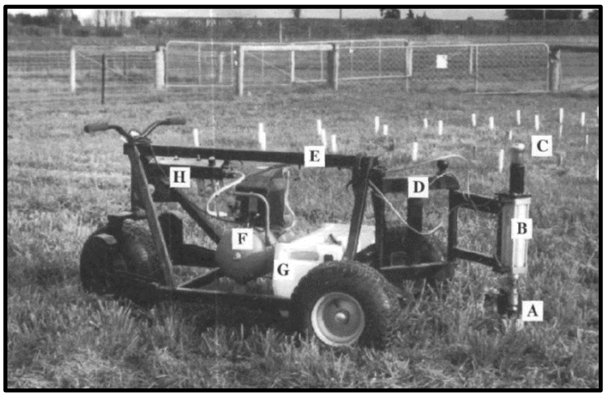

Photo 3: The entire mechanical cow. A, mechanical hoof; B, compressed air ram; C, release button to initiate treading; D, bi-folding arm; E, main body frame; F, air compressor; G, counter weights; H, control panel for treading pressure, speed and duration of hoof-soil contact (Di et al. 2001).

Hoofinator

The ‘hoofinator’ developed by Hu et al. (2018) was constructed by the New Zealand Institute for Plant and Food Research Limited. Its intended application was the simulation of compaction effects that result from the treading of soil by livestock. It was able to apply a range of pressures (147-261kpa) to the soil and the treading covered 100% of the soil surface area. Hydraulic rams with steel plates on the base were forced down onto the soil to create the compaction. Compaction with the hoofinator reduced soil macroporosity and saturated hydraulic conductivity. This device recreated the compaction effects of cow treading well, however failed to cause the lateral damage and smearing of soil associated with cattle treading. The equipment was also highly specialised and thus required sufficient technical competence and a significant amount of work and likely a large cost to construct.

Photo 4: Left: The hydraulic rams and treading plates of the hoofinator (Photo: Richard Gillespie, New Zealand Institute for Plant and Food Research, Lincoln). Right: Treading damage to un-tilled pasture plots by the hoofinator at 261kpa (Hu et al. 2018).

The puggo-stick

The treading in this trial was simulated using a newly fabricated treading device, known as the ‘puggo-stick’ (photo 5). The instrument comprised of a weighted fencepost with a 100mm diameter base. It also had handles and footrests, so it was possible to stand on the device in a manner similar to a pogo-stick (hence its name). The instrument (25.5kg fully loaded) was pressed into the ground with the weight of a human operator (109kg). The hoof had a surface area of 78.54cm^2 and so the impact pressure of the device on the soil surface was approximately 168kpa. This was relatively close to the pressure of a single hoof exerted by a stationary, standing dairy cow (Scholefield & Hall 1986). The operator stepped onto the device in a controlled manner and, attempted to keep the device as vertical as possible while the hoof sank into the soil surface. The puggo-stick cost around $150 (NZ) to construct and was assembled in around two hours, thus satisfying the key criteria of inexpensive and quick to manufacture.

Photo 5: The puggo-stick, with 20kg of weights attached to it.

Materials and Methods

Experimental site - Massey No. 4 Dairy Farm, November 2021

The experimental site included two paddocks with different pasture compositions: 1. Plantain cv. *Agritonic*/ White clover (*Trifolium repens* L.) cv. *Tribute*/ Perennial ryegrass cv. *One*[50]; and 2. Perennial ryegrass cv. *One*[50]/ White clover cv. *Tribute*. Both pastures were three years old.

Treatments.

The treatments consisted of the plantain and perennial ryegrass pastures subjected to three treading damage severities: undamaged (UD), light damage (LD) and heavy damage (HD). Within each pasture type there were 15 plots (three treading treatments, five replicates) of 4 m^2, laid out in a randomised complete block design. The severity of treading damage was governed by the SMC at the time of treading. All plots were watered prior to treading with the intent to reach saturation, which was equivalent to 44% gravimetric water content (GWC), (Howes 2019). The cutting of HD and UD plots and treading of the HD plots was carried out on 1 November. Herbage was cut and removed with a Honda push mower to a height of 5 cm prior to treading. Before treading with the puggo-stick, two square posts were laid down along opposing sides of each plot and a plank was laid across them which extended over the whole plot (Photo 5). This made it possible for the operator to stay off the soil surface and provided a steady base from which the puggo-stick could be stepped onto. The intention was to produce pug marks directly adjacent to one another so that 100% of the soil surface could be treaded. Soil resistance to treading was monitored in the days following the treading of HD plots by measuring the depth of pug marks produced by the puggo-stick in areas adjacent to LD plots. When the mean depth of these pug marks was less than half of those produced in the HD plots, it was determined that enough drainage had occurred and so the risk of damage had fallen sufficiently. On 4 November, the LD plots were cut (as described), and treading implemented.

Measurements

Soil measurements were taken to assess treading damage severity. Pug mark depth (mm) was determined by averaging the three deepest and three shallowest pug marks in three $0.25m^2$ quadrats per plot with a ruler. Pug mark density ($pugs/m^2$) was determined by counting the total number of pug marks within the same quadrat. Soil GWC was measured by collecting four soil cores to 10 cm depth per plot, which were then weighed and oven-dried at 105°C until a constant weight was achieved. Soil GWC data for the UD plots in the PR pasture were missed, so were assumed to be comparable to that of the HD plots in that pasture. Pasture herbage yield was measured on December 1 by hand-clipping three random $0.1m^2$ quadrat cuts per plot to 5 cm height, then drying the herbage at 60°C for 48 hours.

Statistical analysis

Statistical analyses were conducted using the MIXED procedure is SAS (version 9.4, SAS institute 2018). The least squares means test was used for mean comparison and significance was declared at $P<0.05$. Soil GWC, pug depth and pug density were analysed with pasture and treatment as fixed effects, while the herbage yield for each pasture was analysed with treatment as the fixed effect.

Results

Treading damage

Soil GWC, pug depth and pug density were significantly higher in the plantain pasture, in comparison with the perennial ryegrass pasture (Table 1). Soil GWC was significantly higher ($P<0.01$) during the treading of the HD plots, than the LD plots, regardless of pasture type. Pug marks were deeper ($P<0.01$) in HD plots in comparison with LD plots, but LD plots had a significantly higher ($P<0.05$) pug density than HD plots.

Table 1 Mean soil gravimetric water content (%) at the time of treading damage, and the mean pug depth (mm) and pug mark density ($pugs/m^2$) in plantain and perennial ryegrass-based pastures that were subjected to light damage (LD) or heavy damage (HD) with the puggo-stick.

Pasture	**Treatment**	**Soil water content** (%)	**Pug depth** (mm)	**Pug density** ($pugs/m^2$)
Plantain	UD	48	-	-
	LD	42	13	95
	HD	51	35	92
Perennial ryegrass	UD	-	-	-
	LD	36	11	91
	HD	45	18	78
SEM		2.62	1.67	2.83
ANOVA p-values				
Pasture		<0.01	<0.01	<0.01
Treatment		<0.01	<0.01	0.010

Photo 6: Treading damage produced by the puggo-stick in this experiment.

Pasture production

Herbage accumulation was significantly lower (P<0.01) in HD plots in comparison with LD and UD plots, regardless of pasture type. The DM production for plantain and perennial ryegrass pastures was 30% and 32% lower respectively in HD plots than in UD plots.

Table 2 Herbage accumulation relative to undamaged plots (UD) of plantain and perennial ryegrass-based pastures in the 30 days following light treading damage (LD) or heavy treading damage (HD) with the puggo-stick in November 2021. Pasture sown April 2019.

Pasture	Treatment	Herbage accumulation relative to UD
Plantain	UD	100
	LD	89
	HD	70
Perennial ryegrass	UD	100
	LD	103
	HD	68
ANOVA p-values		
Treatment		<0.01

Discussion

Pug depth and thus treading damage severity, increased with an increase in SMC at the time of grazing, which agrees with previous work (Climo & Richardson 1984), and confirms that the treading treatments were implemented as planned. The greater damage severity observed in the plantain pasture was likely a consequence of the higher SMC in those plots during treading, in comparison with the perennial ryegrass pasture, with the difference most likely due to site differences. However, it is difficult to rule out any effect that botanical composition and plant density might have had on the resistance of soil to treading. The likely lower growing point density and higher proportion of bare soil in the plantain pasture relative to the perennial ryegrass pasture may have increased the susceptibility of the former to greater treading damage. The lower pug density recorded for the ryegrass pasture than the plantain pasture may have come as a result of pug marks being less identifiable in the former, since the pug marks were often concealed by plant material. Similarly, pug density may have appeared lower in HD plots due to greater soil displacement causing pug marks to overlap each other, and thus make them difficult to count individually.

The treading damage caused by the puggo-stick was comparable to damage caused by cattle in other studies. For example, Betteridge et al. (2003) reported pug depths greater than 30mm in a saturated silt loam and Nie et al. (2001) reported pug depths of 43mm in a wet clay loam. Furthermore, the effects of puggo-stick damage on herbage production agreed with previously established reductions of between 30-50% following cattle treading (Pande et al. 2000; Nie et al. 2001), which provided further confirmation that the puggo-stick method delivered a reasonable simulation of cattle treading. The effect of puggo-stick stick treading on herbage accumulation was also worsened with an increase in SMC. Treading at a 'safe' SMC appeared to marginally increase herbage accumulation in the ryegrass pasture, but drastically reduce it at an elevated SMC.

There were however, some limitations associated with the puggo-stick; 1. The method required a considerable physical effort on the part of the operator due to its weight and the necessity to move the device for every new pug mark, 2. It was difficult to ensure that every pug mark resulted from an identical exertion of force since that pressure was driven by the operator's physical actions, 3. Being a flat post-end, the force was generally only directed vertically, so any lateral cutting or soil displacement was probably minimal in comparison to that achieved under a walking cow's hoof. However, when considering the likeness of the soil and pasture damage produced by the puggo-stick to cattle treading damage, these limitations appeared to be minor.

Conclusion

The treading damage caused by the puggo-stick was comparable to damage caused by cattle in previous studies, with severity (pug depth) increasing with an increase in SMC. The resulting reduction in the herbage accumulation of both pasture types following damage by the puggo-stick was comparable to the reduction in herbage growth observed by earlier researchers for pastures subjected to cattle treading damage. These results suggest that the puggo-stick generated treading damage comparable to that of live cattle, and so appears to be an inexpensive and effective method for simulating cattle treading damage in pastures and could be considered for use in future experiments.

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