DIVISION S-7—NOTES

A CONSISTENT HOOF IMPACT SIMULATOR

Mark J. Walker,* Raquel Kutsch, W. W. Miller,
Al Cirelli, and Susan Donaldson

Abstract

Studies of the effects of grazing intensity on rangeland vegetation, soil, and water have used mechanical devices to simulate animal trampling. Such studies are often performed at plot scale to allow adequate replication and avoid variability that confounds studies performed at large uncontrolled scales. However, previously applied hoof impact simulators have not been capable of applying reproducible impulse forces on soil. To be useful, simulators must exert a repeatable force, and meet the physical criteria of being lightweight and easily moved between plots. We designed, constructed, and tested a mechanical trampling device that simulated impulse forces from animal hoof impacts with accuracy and precision. Over 3000 individual impacts on soil plots were used to test the device. Hoof impressions on freshly raked loam soil compared well with those from a shod horse. Although tested on plots and in the field with a shod horse hoof replica, it could be easily altered to simulate other animals.

Concerns about soil and water conservation and land resource sustainability have motivated grazing management studies related to rangelands and pastures. Such research examines the effects of animal trampling and potential changes in soil, vegetation, and hydrologic systems. At large scales, such studies lack control over animal behavior, especially traffic patterns in large unconfined areas. In addition, spatial variability in important physical characteristics (for example, soil bulk density, texture, and land surface slope) confounds outcomes of research, particularly with respect to statistical significance of differences in factors that are considered to produce environmental changes. As a consequence, such studies are either observational and retrospective or are performed on a small scale. Because small-scale studies are logistically difficult to carry out with animals, researchers rely on mechanical devices to simulate impulse force applied to soils by hoof impact (Packer, 1953; Dadkhah and Gifford, 1980; Busby and Gifford, 1981; Abdel-Magid et al., 1987). Impulse force is change in momentum with time (Eq. [1]).

$$F = \frac{m\Delta v}{\Delta t} \qquad [1]$$

in which $F \equiv$ force (N), $m \equiv$ mass (kg), $\Delta v \equiv$ change in velocity ($v_{\mathrm{f}} - v_0$, f-final, 0-initial [m s^{-1}]), and $\Delta t \equiv$ the time interval (s) over which the change in momentum occurs.

Previous techniques used to simulate impulse force from hoof impact have been highly varied in their ability to apply and reproduce impulse force from hoof impact. Results from such research may be difficult to extend to larger contexts, especially if impulse force is not clearly defined or reproducible. Impulse force applied by hoof impact can be standardized to provide uniformity for plot-scale research. To accomplish this, a hoof impact simulator should provide consistent and reproducible impulse force precisely and accurately and have the operational characteristics of being portable and relatively inexpensive.

Materials and Methods

Simulator Construction

The design of the simulator arose from studies to assess the effects of pastured shod horses (Kutsch, 2003). The simulator was constructed almost entirely of aluminum to be lightweight (18.1 kg) and portable. Total cost of fabrication was approximately $350. The dimensions were 101 cm in length, 25.4 cm high, and 30.5 cm wide (Fig. 1). These dimensions were partly determined by plot size for a small-scale study (Kutsch, 2003) (Fig. 2), but could be altered to any specification. Rollers mounted on each side of the trampling device allowed movement along the length and width of the study plots, giving an infinite range of positions in the *X*–*Y* plane on the soil surface (Fig. 2). The rollers were mounted above the lip of an aluminum beam, with enough space between lip and beam to accommodate parallel tracks. The tracks, made of angle iron, were bolted to the sides of soil boxes, providing a stable base for application of impacts.

A piston driven by compressed air was used to drive a simulated hoof. Impulse force was controlled using a regulator. A four-way valve extended and retracted the piston, which was equipped with a horse hoof replica, consisting of a size 0 horseshoe mounted on a metal, hoof-shaped plate. The hoof replica was designed to rotate 360°, and a spring was attached to allow heel-first impact, with subsequent rolling to the toe, which is characteristic of both slow and fast gaits (Jones, 1989).

Because the piston assembly can be positioned in an infinite number of positions in an *X*–*Y* plane and the hoof plate can be rotated through an infinite number of orientations, the simulator can be used to represent random or systematic trampling. An application for pasture management studies positioned the hoof replica according to outcomes from a random number generator for *X*–*Y* position, hoof orientation, and number of impacts applied (Kutsch, 2003). A systematic approach would rely on prior development of a spatial pattern and use of markings on the simulator and parallel tracks to reproduce positions for consecutive applications.

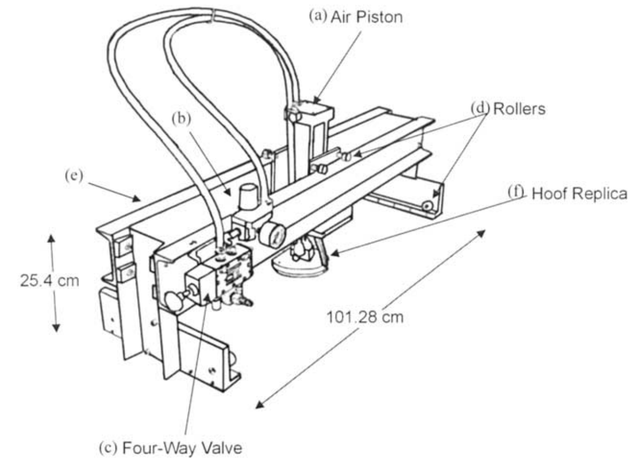
Approach to Adapting Simulator for a Specific Grazing Herbivore

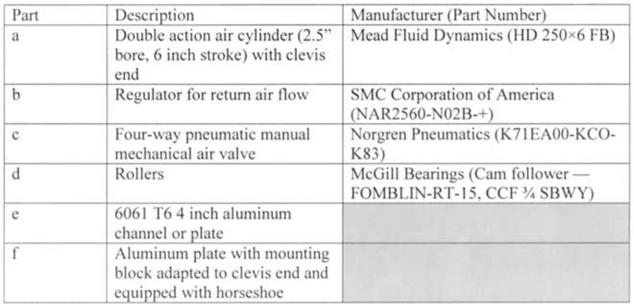
The simulator can be adapted to study the effects of different kinds of grazing animals. As an example, we determined

---

M.J. Walker and W.W. Miller, Dep. of Natural Resources and Environmental Sciences, University of Nevada, Reno, NV 89557 USA; R. Kutsch, Hydrologic Sciences Program, University of Nevada, Reno, NV 89557 USA; A. Cirelli, Dep. of Animal Biotechnology, University of Nevada, Reno, NV 89557 USA; S. Donaldson, University of Nevada Cooperative Extension, Reno, NV 89520 USA. Received 22 Mar. 2004. *Corresponding author (mwalker@cabnr.unr.edu).

Published in Soil Sci. Soc. Am. J. 69:257–259 (2005).
© Soil Science Society of America
677 S. Segoe Rd., Madison, WI 53711 USA





Part	Description	Manufacturer (Part Number)
a	Double action air cylinder (2.5" bore, 6 inch stroke) with clevis end	Mead Fluid Dynamics (HD 250×6 FB)
b	Regulator for return air flow	SMC Corporation of America (NAR2560-N02B-+)
c	Four-way pneumatic manual mechanical air valve	Norgren Pneumatics (K71EA00-KCO-K83)
d	Rollers	McGill Bearings (Cam follower — FOMBLIN-RT-15, CCF ¾ SBWY)
e	6061 T6 4 inch aluminum channel or plate	
f	Aluminum plate with mounting block adapted to clevis end and equipped with horseshoe	

Fig. 1. Mechanical trampling device—schematic view.

several average characteristics of a sample horse population and equipped the simulator to represent the population.

To determine the typical impulse force exerted by a horse's hoof, we estimated the average mass of the population, average hoof circumference and mass distribution between hooves for a walking horse. We observed 21 horses (10 geldings and 11 mares) and estimated mass by encircling the horse's heart girth with a weight tape.

The average mass of the study population was 535 kg (95% confidence interval of ±27 kg). Hood et al. (1994) reported that while standing, a horse typically placed approximately 25% of body mass on each hoof (28% of body weight on each forefoot and 22% on each back hoof). Therefore the mass simulated by the single hoof on the simulator was one quarter of the average mass of the study population (134 kg hoof^{-1}). The average hoof area of the sample population was 110 cm^2 (standard deviation of 3 cm^2).

To determine the appropriate rate of momentum change during hoof impact, we observed height of lift of a hoof while walking. At the apex of a stride, the distance from the base of the hoof to the soil surface was, on the average, approximately 9 cm. The average walking stride of a horse lasts for approximately 0.8 to 1.1 s (Back and Clayton, 2001), which indicated a vertical velocity of approximately 0.1 to 0.2 m s^{-1}. The simulator hoof vertical velocity (v_0 in Eq. [1]) was slightly higher (0.3 m s^{-1}). Therefore, the impulse force applied by a shod horse was estimated as 134 N, with v_f considered to be 0 m s^{-1}, and $\Delta t \approx d/v_0$, or 0.09 m/0.3 (m s^{-1}).

Reproducibility Within and Between Trials

One of the goals of developing the simulator was related to reproducibility of the simulated mass of a horse within and between trials. The latter characteristic was important with respect to long-term application for experiments with repeated measurements. To assess reproducibility, we measured accuracy and precision of estimated applied mass with 30 trials at the mean and upper and lower bounds of the study population (with target simulated masses of 79, 135, and 147 kg hoof^{-1}), using a digital scale. We assessed reproducibility at the beginning of trials and at the completion of experiments, after the simulator had been used to apply over 3000 impacts. We also applied the simulator in a field setting, with freshly tilled and raked soil, to compare compaction from impulse forces applied with the hoof simulator with those observed from a horse.

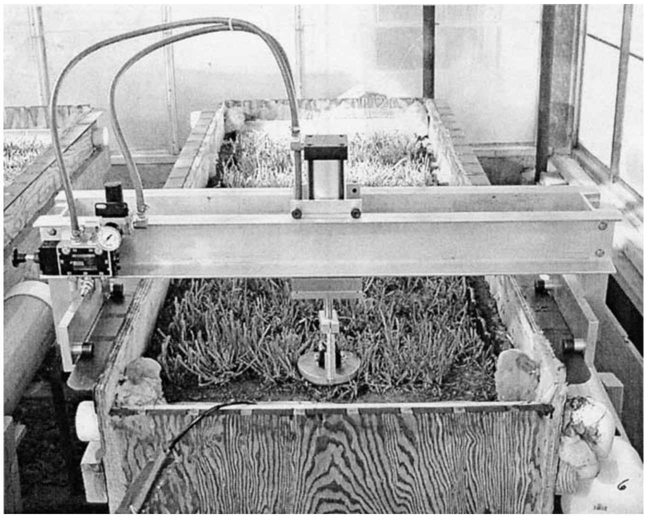


Fig. 2. Mechanical trampling device on tracks for use on small plots.

Results and Discussion

Mean simulated masses recorded before a year and a half of trials (Kutsch, 2003) were 79 kg (with a 95% confidence interval of ±0.2 kg), 135 ± 0.2 kg, and 147 ± 0.3 kg ($n = 30$ trials), which indicate highly precise and reproducible simulated masses. A year and a half after the first trials, after the simulator had applied approximately 3000 impacts for experimental purposes, simulated masses applied at the same air pressures were 75 (with a 95% confidence interval of ±0.8 kg), 133 ± 0.6 kg, and 144 ± 0.2 kg ($n = 30$ trials). The simulated masses remained extremely precise, but accuracy changed, relative to the expected simulated mass at the selected pressures. This indicates a need for calibration before application and periodic calibration during experiments to ensure consistency throughout.

Field Trials: We conducted field trials with the simulator to compare the effects of horse hoof and simulated horse hoof impulse force applications on a freshly tilled raked loam soil. The trial was based on several traverses by a 386-kg horse led at a slow walking gait through a section of raked soil 1.83 m in length (Fig. 3a). Horse mass was estimated using a heart-girth tape. Soil compaction because of the application of impulse force by hooves was characterized by measuring the impression depth (Fig. 3b) from the soil surface at five randomly selected sites within the depression and expressing the result as the average. The simulator was then installed immediately adjacent to the hoof depressions (Fig. 3c) and calibrated to apply a mass of 96 kg, to simulate the

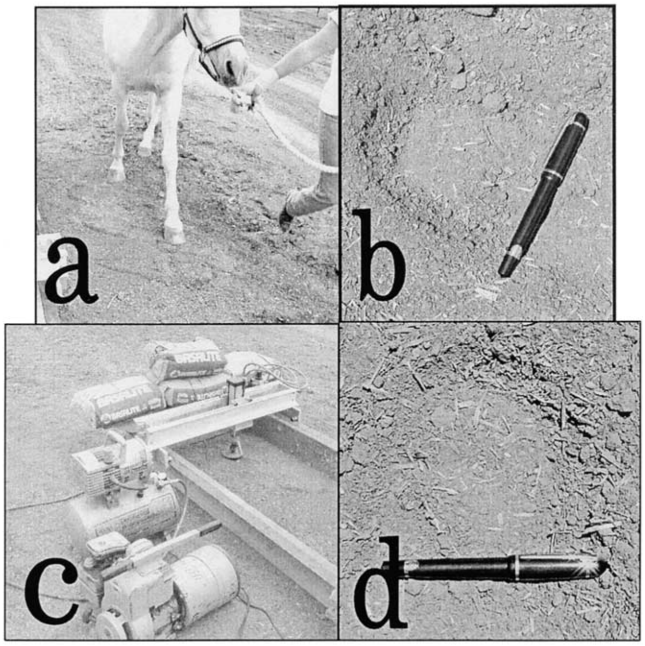


Fig. 3. Field trials for comparison with horse hoof impulse force: (a) 386 kg horse traversing plot, (b) typical impression from horse hoof, (c) trampling device on adjacent plot, (d) typical impression from trampling device.

estimated mass borne by a single hoof. The simulator was then used to develop hoof impressions (Fig. 3d).

Average depth of depression left by the horse hoof was 1.3 cm (0.5 inches), with a standard deviation of 0.6 cm (0.3 inches) ($n = 5$). The standard deviation is due in part to microvariations in soil, variations in impression depth associated with shod and unshod hoof surfaces and the horse's gait across the plot. The average depth of impression left by the simulator was 1.3 cm (0.5 inches) with a standard deviation of 0.6 cm (0.2 inches) ($n = 5$). Standard deviation in depression depth was slightly decreased relative to that calculated from trials with the horse, but still reflects differences in the shod and unshod surfaces of the simulated hoof. However, the simulator did not have the same range of motion and variability that might be expected from an actual horse's hoof. Impressions left by the simulator are unlikely to be as variable as those left by a horse because the simulator cannot reproduce small variations in impulse force that could be due to differences in horse movement and corrections to maintain balance over uneven surfaces.

Conclusions

The use of compressed air provided a high degree of control over impulse force and allowed accurate and precise positioning and consistency in simulated mass. The aluminum construction was lightweight and easily moved by one person, and was applied for plot and field trials. Limited comparisons with hoof impressions left by a horse on freshly raked soil indicated that simulated and real hoof impressions were the same, with respect to average depth of the impression. Although the simulator does not perfectly replicate impulse force applied by a horse's hoof, it provides a consistent impulse force that was demonstrated to leave hoof impressions that were the same depth as those created by a horse.

The simulator can be modified for study of hoof impact by ungulate herbivores such as cattle, sheep, goats, elk, or deer. This could be accomplished by recording important physical characteristics of a sample population and transferring these characteristics to the simulator. For example, to faithfully replicate a steer hoof, Abdel-Magid et al. (1987) used a bronze cast. Similarly, Sigafoos (1989) described a technique for molding horse hooves using dental alginate impression material.

At a cost of approximately $350.00, the mechanical trampling device simulates hoof impact, exerts a repeatable force, is lightweight, portable, and adaptable for many types of animal impact research. The design incorporates control and versatility, and provides consistency and reproducibility that may otherwise be difficult to achieve.

Acknowledgments

This work was supported by the Nevada Agriculture Experiment Station, Project Number 0532E. We also acknowledge Wade Cline, Senior Development Technician, of the University of Nevada, Reno Physics Machine Shop, who designed and constructed the mechanical trampling device.

References

Abdel-Magid, A.H., M.J. Trlica, and R.H. Hart. 1987. Soil and vegetation responses to simulated trampling. J. Range Manage. 40:303–306.

Back, W., and H. Clayton. 2001. Equine locomotion. Harcourt Publishers Limited, London.

Busby, F.E., and G.F. Gifford. 1981. Effects of livestock grazing on infiltration and erosion rates measured on chained and unchained pinyon-juniper sites in southeastern Utah. J. Range Manage. 34: 400–405.

Dadkhah, M., and G.F. Gifford. 1980. Influence of vegetation, rock cover, and trampling on infiltration rates and sediment production. Water Resour. Bull. 16:979–986.

Hood, D.M., J.F. Hunter, W.D. Beltz, B.E. Taylor, A.S. Beckham, and J.R. Pierce. 1994. Digital loading patterns in the normal standing horse. p. 37–38. *In* Proc. from the Twelfth Meeting of the Association for Equine Sports Medicine. 13–16 Mar. 1993. Veterinary Practice Publications, Santa Barbara, CA.

Jones, W.E. 1989. Locomotion. p. 149–187. *In* Equine sports medicine. Lea & Febiger, Philadelphia, PA.

Kutsch, R. 2003. Hydrologic responses to simulated small ranch conditions of horse grazing/trampling and flood irrigation. M.S. Thesis, Dep. of Environmental and Resource Sciences, University of Nevada, Reno.

Packer, P.E. 1953. Effects of trampling disturbance on watershed condition, runoff, and erosion. J. Forestry 51:28–31.

Sigafoos, R. 1989. Obtaining an accurate hoof mold: A simple impression technique. American Farriers J March/April:18–21.