A protocol for rapid evidence synthesis into soil loosening as an intervention to ameliorate compaction caused by dairy farming and the impacts of this for productivity and sustainability

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Abstract

This is a protocol for a rapid review of the effectiveness of soil loosening to ameliorate compaction caused by cattle treading from dairy production on UK dairy farms. The review will synthesize relevant literature that explores the impacts that can be derived from mechanical soil loosening for improved soil quality, productivity (i.e. yield) and the environment. The protocol outlines the rationale, objectives, inclusion criteria, search strategy and screening processes for the meta-analysis, and the plans for data extraction, risk of bias and data synthesis approaches.

1. Protocol

1.1 Introduction

Soil compaction is significant cause of soil degradation globally (Drewry and Paton, 2000, FAO, 2015, Smith et al., 2013, Wentworth, 2015) Compaction results in the underlying soil structure being unable to withstand the pressures applied to it. Compression leads to coarsening of the soil, loss of the structural units of the soil, decrease in soil volume (erosion), an increase in bulk density, decrease in porosity and a reduction in the hydraulic capacity of the soil (NFU, 2016, DEFRA, 2008, Newell-Price et al., 2013). Soil structures and quality vary according to soil type (i.e. clay, sand, silt, loams and peat) and location with varying levels of susceptibility to compaction damage (Bezuidenhout, 2010, Drewry, 2006, DEFRA, 2008, Wentworth, 2015, Drewry et al., 2004, Newell-Price et al., 2013). The macroporosity of soil (the volume of pores) is used by experts as an indicator of soil compaction. In arable land compaction and the reduction of soil macroporsity (below 10%) represent poor aeration and results in cultivation difficulties as a result of restricted water and nutrient delivery, and reduced earthworm abundance (Drewry and Paton, 2000, Chan and Barchia, 2007) that are difficult, time consuming and expensive to remedy (Bezuidenhout, 2010). In terms of empirical research, a greater body of research has explored the causes and consequences of soil compaction on arable soils rather than grasslands and much of the research conducted to-date originates from New Zealand, Australia and the US (Drewry and Paton, 2000, Singleton and Addison, 1999, Clark et al., 2007, Greenwood et al., 1997, Naeth et al., 1990, Chan and Barchia, 2007) with limited research conducted in a UK context (DEFRA, 2008). Within this body of literature, key causes of soil compaction in agricultural production are related to farm machinery and cattle grazing, where the weight of soil machinery and cattle compress the soil ((DEFRA, 2008, Newell-Price et al., 2013).

Cattle grazing is central to dairy production and dairy farming is identified to be one of the most significant contributors to soil compaction ((DEFRA, 2008, Newell-Price et al., 2013). The cumulative impact of cattle treading on soil compaction rates has been well documented and is recognised to cause the most visual and structural damage to soil surfaces (0-10 cm depths (DEFRA, 2008) (see inter alia ((Drewry and Paton, 2000, Singleton and Addison, 1999, DEFRA, 2008, Wentworth, 2015). Sustained grazing and trampling of the soil by cattle results in surface damage with less damage occurring at deeper soil levels. In the UK, the average time that cattle spend grazing has increased over recent years from 7 months in 2006 to approximately 9 months in 2010. Change has been underpinned by increasing feed prices and the availability of early/late season grass and clover species and the increasing trend for out-wintering cattle (Newell-Price et al., 2013). Soils vulnerability to structural damage caused as a result of cattle trampling is subject to seasonal variations and is most susceptible during the spring and autumn periods although, predisposed soils can also become more exposed at times of high average rainfall when structural damage to the soil termed “pugging” or “poaching” can result (DEFRA, 2008).

When animal hooves penetrate the surface of soils “poaching” occurs, this can arise across fields although is often most pronounced around high-traffic areas within fields (i.e. around feeding and water trays). Both cattle and sheep grazing can cause poaching that results in soil compaction, although this occurs at greater intensity as a result of cattle grazing owing to the increased pressures (kilopascal (kPa)) of cattle hooves, the volume of which differs between static positions and when livestock is moving (Bilotta et al., 2007). To illustrate the impact of cattle grazing it is useful to compare this to the impacts of sheep grazing. Sheep exert approximately 80kPa which increases to 200kPa when moving. However, when static the pressure exerted by cattle ranges from 160-192kPa, when in motion this more than doubles (DEFRA, 2008).

Pugging occurs in wet conditions when soil pores fill with water significantly reducing the macroporosity of soil. When cattle graze on saturated soil the soil structure can homogenise, visually this results in lumpy and irregular surface and in extreme cases can result in slurry (Parkes and Faulkner, 2013). Reduced macroporosity as a result of pugging has been show to negatively affect plant production and the profitability as well as the sustainability of pastoral farms (Burgess et al., 2000). Monitoring of soil compaction on dairy farms in New Zealand has shown that a macroporosity value of <10% is likely to limit pasture production and in severe cases could reduce this reduce production by 40-80%. Sever pugging events occurs most during winter when block grazing occurs and cows are not being milked and soil recovery is less effective than in spring and summer months (Parkes and Faulkner, 2013, Drewry et al., 2004). Stocking density (i.e. the number of cows grazing) per hectare, is shown to be further compounding factor in compaction rates, with increased cattle numbers shown to have a

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positive relationship with soil compaction (Greenwood et al., 1997, DEFRA, 2008, Naeth et al., 1990).

Despite a plethora of studies that have illustrated the detrimental effect on soil of cattle treading, there is limited research that has been conducted to explore ways in which the impact of this might be ameliorated (Burgess et al., 2000). Modifications to agronomic practice are such as amendments to grazing management frequency and timing are thought to minimise compaction ((Greenwood et al., 1997, Parkes and Faulkner, 2013, Drewry et al., 2004). Restorative measures of which mechanical soil loosening is an example, have been studied less widely. Mechanical loosening of the soil in order to break up compacted soils is a strategy for the amelioration of soils that have been degraded as a result of cattle treading. In a study conducted on two New Zealand dairy farms, Burgess et al. (2000)found that when compared to non-aerated soils, mechanical loosening was advantageous in that it increased macroporosity and total porosity and hydraulic conductivity as well as reducing water penetration resistance the degree of packing and bulk density and improved conditions for plant root growth. Reversion of the benefits of aeration occurred in the sample site after 40 weeks and therefore the research illustrated the need for this action to be repeated annually. Such interventions that are designed to reduce compaction and increase soil quality deliver direct economic benefits to farmers as well more widely to the rural communities in which they are embedded, as well as society as a whole through improved food quality and availability. Such practices also deliver wider conservation benefits through the delivery of additional ecosystem services, including improved responsiveness to flooding events, increased biodiversity and carbon and nitrogen regulation.

1.2 Need for the review

This rapid evidence review aims to explore the impacts of mechanical soil loosening to ameliorate soil compaction as an intervention to improve 1) productivity and 2) sustainability in UK dairy farming. A number of studies have indicated the effectiveness of mechanical soil loosening as a restorative intervention against soil compaction, caused by large ruminant grazing including dairy production (Drewry and Paton, 2000, Burgess et al., 2000). Soil is a fundamental eco-system services, protecting it and restoring it where degradation has occurred has potential to ensure the productivity and sustainability of UK dairy farming. However, there has been no formalised evaluation of the extant body of literature and the strength of evidence of the effectiveness of mechanical soil loosening for improved dairy farm productivity and sustainability has not been assessed.

This rapid evidence review will therefore, make a number of substantive contributions; to the best of the authors knowledge this is the first time that published evidence of the effectiveness of this intervention for improving soil quality has been synthesised. From a policy perspective this will formalise the evidence base upon which decisions regarding the promotion of mechanical soil loosening as an 'Payment for Ecosystem Services' intervention, can be made. From an academic perspective evidence synthesis supports the identification of knowledge gaps and helps to direct future research agendas.

2 Objectives

2.1 Primary objective:

To evaluate the effectiveness of mechanical soil loosening to ameliorate soil compaction caused by cattle grazing in diary production systems and the impacts of this intervention for;

1) Improved productivity (yield) and sustainability (i.e. improved soil quality and biodiversity) of dairy farming.

2.2 Secondary objective:

A number of secondary outcomes will also be examined and will be used to explore the reasons for heterogeneity in the primary outcomes of the study. These include the impacts of the following on the effectiveness of mechanical soil loosening;

- Soil type
- Herd size/stock density
- Compaction depth
- Soil saturation
- Seasonality/weather conditions
- Grazing management system
- Intervention frequency

2.3 Tertiary outcome:

1) Measurements of the economic impact of soil loosening by mechanical means

3 Criteria for considering studies for the review

Studies obtained from the search will be selected based on the eligibility criteria outlined in Table 1, any studies not meeting the inclusion criteria will be excluded. These are outlined in more detail in the subsequent sections and are based on the PICO (population, intervention, comparator, outcome) format.

Table 1: Inclusion/exclusion criteria

Inclusion criteria	**Exclusion criteria**
Empirical (quantitative) studies conducted between 1986-2018 in English language.	A non-empirical study i.e. review article or posters or abstracts that were not followed up by full publication, a non-English language study or published prior to 1986.
studies with a comparator (i.e. adoption versus non-adoption or a before/after temporal comparison)	Studies without a comparative component.
Report on the impacts of compaction caused by cattle treading of farm machinery	Report on the impacts of compaction not caused by animal treading or farm machinery
Report on impacts of soil loosening for productivity and/or sustainability in temperate grassland systems	Report on the impacts of soil loosening in non-temperate grass land systems
	Studies that examine methods or refine tools for soil compaction alleviation
Studies must include sample size and mean values to facilitate effect size generation.	Studies that do not report sample size and mean values to enable effect size generation.

3.1 Searches:

Web of Science will be searched as well as Google Scholar in order to identify any grey literature. Searches will cover all studies published over the past 32 years. Firstly, reference lists of retrieved studies and reviews will be checked for additional studies not returned from the initial searches. Secondly, key authors/organisations in the field will be consulted to check for any unpublished findings and additional sources of information (Green and Higgins, 2005).

3.2 Search strategy:

Search terms will be refined after trial searches are conducted, tailored to each database, to balance sensitivity and specificity. The search strategies will be reported in an appendix in the final review. The following search terms will be used. All search terms will be included in the topic, keyword, title and abstract sections of each individual database searched and used in conjunction with the Boolean operator AND as highlighted. Keywords in relation to the comparator were not used as they were too generic and risk returning irrelevant papers.

The following search terms will be trailed:

(livestock OR cattle OR ruminant) AND ((Soil compaction) OR pugging OR poaching OR treading) AND ((Soil loosening) OR (mechanical soil loosening) OR subsoiling) AND (productivity OR yield OR sustainability OR (soil quality) OR macroporosity OR (bulk density) OR (hydraulic conductivity) OR (plant root growth))

3.3 Domain of Study:

A number of studies have indicated the effectiveness of mechanical soil loosening as a restorative intervention against soil compaction, caused by large ruminant grazing including dairy production (Burgess et al., 2000, Drewry and Paton, 2000) Soil is a fundamental eco-system services, protecting it and restoring it where degradation has occurred has potential to ensure the productivity and sustainability of UK dairy farming. However, there has been no formalised evaluation of the extant body of literature and the strength of evidence of the effectiveness of mechanical soil loosening for improved dairy farm productivity and sustainability has not been assessed.

This rapid evidence review will therefore, make a number of substantive contributions; to the best of the authors knowledge this is the first time that published evidence of the effectiveness of this intervention for improving soil quality has been synthesised. From a policy perspective this will formalise the evidence base upon which decisions regarding the promotion of mechanical soil loosening as an PES intervention, can be made. From an academic perspective evidence synthesis supports the identification of knowledge gaps and helps to direct future research agendas

3.4 Participants/population:

Studies conducted in any geographical region that assess the impact of mechanical soil loosening as a method for the amelioration of soil compaction caused by cattle treading and impacts of this for productivity and sustainability within temporal grassland systems.

3.5 Intervention(s)/exposure(s);

Any studies that have adopted mechanical soil loosening as an intervention to ameliorate soil compaction caused by cattle treading and the impacts of this for productivity within temporal grassland systems.

3.6 Comparator(s)/control:

Studies will be included on the basis that they report on 1) adoption versus non-adoption and/or 2) temporal comparisons (i.e. before and after).

4 Method of the Review

4.1 Data extraction:

All search results will be exported into an EndNote library, with duplicates being removed before results are sifted according to the inclusion and exclusion criteria outlined in Table 1. An overview of the search process will be included in a PRISMA flow chart (Moher et al., 2009). The returned search results will then be filtered in a two -stage process as follows:

> Stage 1) Title and abstract screening: In addition to the full title the abstract of these studies will also be read so as to minimise the risk of error (Green and Higgins, 2005). HK will review all studies, with a subset of at least 10% independently assessed by two reviewers (HK and AT). Any differences between the two researchers will be reported and resolved through discussion.
>
> Stage 2) Full text screening: the full text of all included studies will be read and assessed for relevance by the primary researcher (HK)A subset of at least 10% cross

checked between two reviewers (HK and AT). Any differences in decisions related to study eligibility will be recorded and discussed by the review authors.

4.2 Risk of bias (quality) assessment

The validity and the impact of bias will be addressed by use of a critical appraisal document(s) that examines a number of quality criteria which have the potential to impact on the results of the study. Critical assessment will consider the construct validity, internal validity and reliability of included studies, as described by Yin (2009).

The quality appraisal tool will be modified from the Newcastle-Ottowa scale (NOS) to provide a checklist that meets the emerging requirements of the review and suitable quality assessment of non-medical research literature. (Green and Higgins, 2005), Campbell Collaboration (2001) guidelines and the Centre for Reviews and Disseminations (2009) advice, to provide a document not based in a healthcare context. The critical appraisal tool will be finalised prior to data extraction.

No studies will be excluded based on the quality assessment tool, but the findings will be taken into account during the evidence synthesis as part of the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) framework, (Meader et al., 2014) which will assess the overall of strength of evidence, and may inform sensitivity analysis. Any differences in decisions related to study quality will be discussed by the review authors

4.3 Strategy for data synthesis

A data extraction form will be used to extract data from all included studies (excel), and this will be finalised as the nature of the data becomes apparent. The finalised data extraction form will be trialled, to check that all relevant information is extracted. A template of the final form will be attached to the final review,

All data will be extracted by the primary researcher (HK), a subset of at least 10% of the included studies will be checked independently by a second reviewer (AT), again to check for potential errors. Where information is missing efforts will be made to contact the authors to obtain further details (Green and Higgins, 2005).

An overview of all included studies will be provided in an appendix. Descriptive statistics, such as a summary of the study characteristics, will first be presented in the results. Synthesis of the data will depend on the nature of the included studies.

If we have a sufficient number of high quality studies a random effects meta-analysis will be carried out using (standardized) mean difference. In order to do this, we will collect data on means, standard deviations, and the number of replicates. Sensitivity analyses will be performed to explore the risk of bias and a funnel plot will be used to detect potential publication bias. If we do not have a sufficient number of high quality studies, we will use the diverse set of literature in order to identify and evaluate reported outcomes.

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