CLIMATE-POSITIVE FARMING REVIEWS

The James Hutton Institute

Unravelling the terminology and impacts of rotational grazing – what evidence is there for environmental benefits?

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Executive Summary

This review unravels the terminology and impacts of rotational grazing, with a particular focus on the evidence available to demonstrate environmental benefits, particularly in relation of climate positive farming systems. Rotational grazing is thought to contribute to sustainable livestock production, however rotational grazing is a very broad concept. Here we looked at the broad range of definitions for this grazing practice to assess its benefits for livestock production, farm economics and the wider environment.

Key findings from the review include:

- Rotational grazing is an umbrella term for a selection poorly defined repeated graze-rest grazing regimes.
- It is inappropriate to compare studies based purely on named grazing regimes due to inconsistences in definitions. Rotational grazing regimes should be compared based on the intensity of the rotational system, considering both the length of the grazing periods and rest periods.
- Theoretical benefits of rotational grazing include improvements to soil, forage quality, drought resilience of the sward, healthier animals which produce less methane, enhance biodiversity throughout the trophic levels whilst maintaining economically viable livestock systems.
- Support for the theoretical benefits was weak or absent in many cases, as follows:
    - Rotational grazing with a long rest period generally enhanced soil carbon storage from the few studies found.
    - Empirical studies measuring root systems were lacking.
    - There were no consistent impacts on plant species composition, forage biomass production and vegetation quality under rotational grazing regimes, but again the data were scarce.
    - There were few studies and little evidence that rotational grazing mitigates greenhouse gas emissions.
    - There were insufficient studies to determine whether rotational grazing benefits animal health.
    - The few studies found on financial impacts of rotational grazing had mixed findings.
    - There was only anecdotal evidence of enhanced biodiversity under rotational grazing systems.
- The literature revealed a wide range of different rotational systems with limited replication across studies.
- The studies had a wide geographical spread with different grassland types, climates, and soils at each of the study sites.
- All empirical studies found compared rotational grazing regimes in systems very different to those found in the UK.
- We found insufficient evidence available to conclude whether any particular rotational system was better than another.

1. Introduction

Harnessing the power of the sun though careful pasture management is key to sustainable livestock production. Rotational grazing, in its many guises is a technique which is believed to help achieve this. It has received heightened interest over recent times as both theoretical and anecdotal evidence suggests that it can play an important role in climate-positive farming and provide wider biodiversity benefits. However, rotational grazing is a broad concept and the terminology used to describe this technique is far from clear, making it difficult to compare like with like and assess the perceived benefits of this grazing regime. Here we try to disentangle the terms used to describe rotational grazing in order to make an assessment of its benefits for livestock production, farm economics and the wider environment. Particular attention is paid to the role of rotational grazing in climate-positive farming systems.

2. Defining rotational grazing

Broadly speaking, *rotational grazing* is a grazing technique, whereby animals are moved through a series of 3 or more paddocks, allowing a period free from grazing where the pasture is able to recover before being subject to future grazing episodes (Allen et al., 2011). This grazing method falls along a continuum of grazing regimes, which can be ordered as follows. *Confinement feeding* requires the animals to be kept inside throughout the year (Fredeen et al., 2002, Alvez et al., 2014). Here land is only used to produce grass and cereals which are preserved for feeding the animals. S*et stocking* is often the conventional grazing system used in the UK, this aims to keep livestock on the same pasture at a low stocking rate throughout the grazing period. In this case the grazing period is generally determined by the availability of grass and how wet the ground is. When the animals are not able to graze outside, they are housed and fed conserved forage which is either grown on farm or bought in. *Rotational grazing* can be considered as an umbrella term for a selection of overlapping and poorly defined, repeated graze-rest grazing regimes, including mob grazing, holistic grazing, cell grazing, strip grazing, management intensive grazing (MIG), ultra-high stocking density grazing, adaptive multi-paddock grazing (AMP) and time-controlled grazing (See Figure 1). Many farmers use these terms interchangeably (McCosker, 2000, Nordborg, 2016). However, generalisations can be made about their position along the continuum as indicated in Fig. 1.

When perusing the literature and accounts of farmers grazing regimes it becomes apparent that the term '*rotational grazing'* encompasses a variety of techniques which differ in the following 4 main areas:

- The number of paddocks used
- The size of the paddocks
- The length of the grazing period
- The length of the rest period

Furthermore, the grazing period can either be determined by calendar date or by assessment of the pasture. The latter can be achieved by taking measurements of residual sward height or forage dry matter content. This information can then be used to determine the best time to move the animals to new pasture (Teague and Barnes, 2017, Brink et al., 2013, Richards and Lawrence, 2009). Similarly, the rest period of paddocks can also be adjusted based on season and rate of vegetation growth (Brink et al., 2013, Hodbod et al., 2016).

When these factors are taken into account, we can generalise that 'standard' or 'traditional' rotational grazing uses a higher stocking density than set stocking and the animals are often moved between paddocks at predefined times. The grazing period in each paddock may be days-weeks followed by a relatively short rest period (a month or less). This is subtly different to mob grazing, cell grazing, strip grazing, ultra-high stocking density grazing and management intensive grazing (MIG) where the stocking density is normally higher, often the result of much smaller paddocks, the grazing period shorter (frequently 1 day or less) and the rest period before re-grazing longer (2 months to a year). In many cases the grazing period and rest period are adjusted based on pasture assessment rather than calendar date. This is especially the case for adaptive multi-paddock management (AMP) and holistic grazing. This makes it particularly difficult to provide a definitive definition of these rotational grazing regimes and probably explains why they are often poorly defined in the literature. For this reason, when assessing the impact of a particular rotational grazing technique it is important to consider the number of paddocks used, the size of the paddocks, the length of the rotation, and the length of the rest period when making comparisons, as the name assigned to the grazing regime may be ambiguous. A selection of definitions from the literature is included in Appendix I to demonstrate the inconsistencies in terminology.

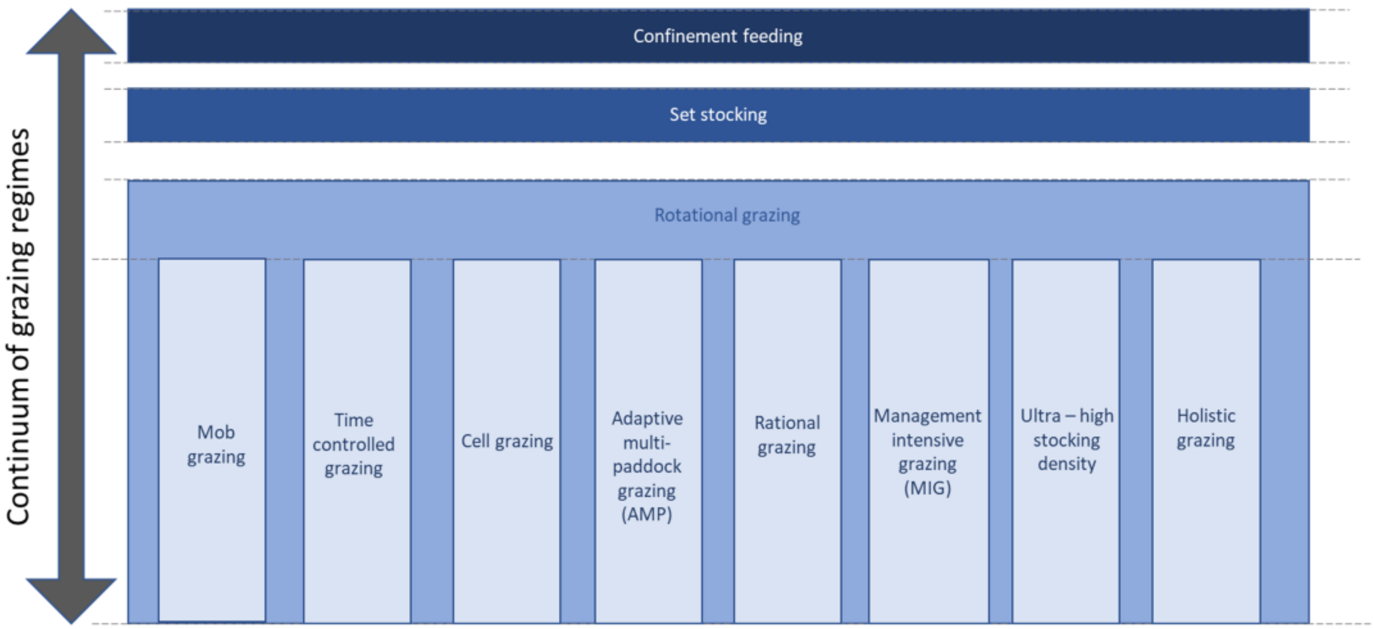

Figure 1. Continuum of grazing regimes.

3. Rotational grazing influences

Allowing a pasture a period free from grazing, to enable the plants to recover and re-grow in order to sustain subsequent grazing episodes, is central to all rotational grazing systems. André Voisin (1903-1964), a French biochemist and farmer, is probably the greatest influencer on this grazing technique. His first law, of what he referred to as '*rational grazing',* rather than rotational grazing, states that: *"Before a sward, sheared with the animal's teeth, can achieve its maximum productivity, sufficient interval must have elapsed between two successive shearings to allow the grass to accumulate in its roots the reserves necessary for a vigorous spurt of re-growth"* (Worstell and Voisin, 2015). This law recognises the importance of a long recovery period; and we see this incorporated into the grazing plans of those who practice the more intensive forms of rotational grazing such as mob, MIG and cell grazing.

Intensive rotational grazing also aims to mirror natural systems where native herbivores move together in large groups, offering each other protection from predators. The animals are constantly on the move, grazing as they go and leaving behind a vast expanse of trampled vegetation, covered by dung and urine, both of which become incorporated into the soil, enhancing soil structure and fertility. The animals do not return to the same area for many days, even months, allowing the plants to re-grow and establish strong root systems. In 2013 Allan Savory (1935-present), a Zimbabwean ecologist and farmer, gave a lecture entitled "How to green the world's deserts and reverse climate change", in which he advocated mimicking natural grazing patterns in order to improve soil structure, fertility, water holding capacity and carbon storage potential, thus creating suitable conditions for plant re-establishment (Savory, 2013). His ideas were met by much criticism, due to a lack of scientific evidence to support his claims (see Nordborg (2016)). Yet he has still influenced a lot of thinking behind intensive rotational grazing systems, particularly holistic grazing.

4. Theoretical benefits of rotational grazing

4.1. Soil

The short grazing period common to many rotational grazing systems means few plants are re-grazed during any single grazing period, and generally some plant material remains ungrazed. This can often be up to 40% of the sward and mainly consists of stems (Jones, 2000). About half of this can be trampled into the ground by the grazing animals (Jones, 2000). Trampled vegetation is believed to add organic matter to the soil, improve water holding capacity when dry and improve drainage when wet, as well as contributing to soil carbon storage. Furthermore, the root material, which may be extensive under rotationally grazed pastures (see below), may provide a rich food source to sustain and enhance soil microbial activity (Jones, 2000). The concentrated deposition of dung and urine from sheep and cattle is likely to increase soil nutrients.

4.2. Sward composition and forage quantity and quality

In rotational grazing systems, where animals graze a confined area which has tall grass on entry, the high stocking density limits the animal's ability to graze selectively. The animals have less choice between the individual plants and parts of the plants which they graze. This means they are likely to eat both the highly digestible leafy material and the stems/flower heads (Chapman, 2021). This should lead to the paddock being grazed more evenly with both the most desirable species and those which are less preferred being consumed by the animals (Havard, 2018). This should prevent the less palatable species from having a competitive advantage and becoming dominant in the sward (Havard, 2018). This is thought to encourage greater sward diversity, further enhancing the nutritive value of the forage (Wang et al., 2015).

It has been shown that the plant material above ground mirrors the root system below ground (Jones, 2000). Therefore, a tall grass pasture is likely to have a much deeper and more extensive root system than a closely grazed sward (Figure 2c). This would allow the plants to access water and nutrients from deep in the soil. In rotationally grazed pastures, where grazing is likely to be non-selective, the reduction in foliage of all plants leads to a reduction in their ability to photosynthesize and subsequently a reduction in the size of the root systems they are able to support (Figure 2b). However, following a long rest period, which is often included in rotational grazing systems, the plants have an opportunity to regrow, photosynthesize and produce sugars, which helps them to develop strong, complex root systems (Figure 2c). This rest period is thought to be important for sustaining the sward. Contrast this with continuously grazed pastures where the most desirable species are likely to be selectively grazed, reducing their foliage and root system, whilst the less palatable species can grow bigger and stronger (Figure 2a). Continuous grazing rarely provides the opportunity for the grazing-favoured species to recover. The resulting small root systems will limit their access to soil nutrients and water, making them also more susceptible to drought conditions. The weakened plants will be less able to survive, thus leading to a gradual reduction in their cover and a sward increasingly dominated by less preferred species (Jones, 2000).

4.3. Greenhouse gas emissions

Ruminant livestock are known to be a major contributor to greenhouse gas emissions, and intensive rotational grazing is thought to be a way to reduce and mitigate these effects. This is based on the premise that intense rotational grazing may, in some cases, lead to improved vegetation quality and hence higher feed digestibility, which in turn is thought to reduce the amount of methane produced through enteric fermentation (Wang et al., 2015). However, this benefit may only be realised if an appropriate sward mix is chosen which will lead to the production of high-quality forage. Furthermore, where rotational grazing leads to higher sequestration of carbon in soils, some methane emissions maybe offset.

4.4. Animal Health and production

The diverse pastures which may arise as the result of rotational grazing could provide natural de-worming properties leading to healthier animals (Fir Farm, 2021). The selection of breeds (generally smaller or traditional breeds) which are better suited to rotational grazing systems is thought to increase the viability of the livestock enterprise (Havard, 2018).

4.5. Biodiversity

In rotational systems, once the animals are moved onto fresh pasture the grazed paddock is allowed a recovery period before being subject to further grazing. The length of the recovery period generally depends on the intensity of the rotational grazing regime, but a long recovery period which coincides with flowering time has the potential to create swards which are a rich nectar source for pollinators, a source of seed for pasture maintenance and a favourable habitat structure for some nesting birds, insects, and voles (Soil Association Scotland, 2018). This could provide further benefits at higher trophic levels for species which feed on these animals.

4.6. Economics

It is important to ensure that any grazing regime is financially viable. In some cases, rotational grazing may lead to lower productivity (Phillip et al., 2001). However, this could be counteracted by lower production costs if the land is used more efficiently with a higher stocking rate and an appropriate breed is selected. Rotational grazing could also extend the total annual grazing period, reducing the need for straw and winter feed as well as improving sward persistence, reducing the need for re-seeding (Chapman, 2021). All these factors would ultimately save the farmer money.

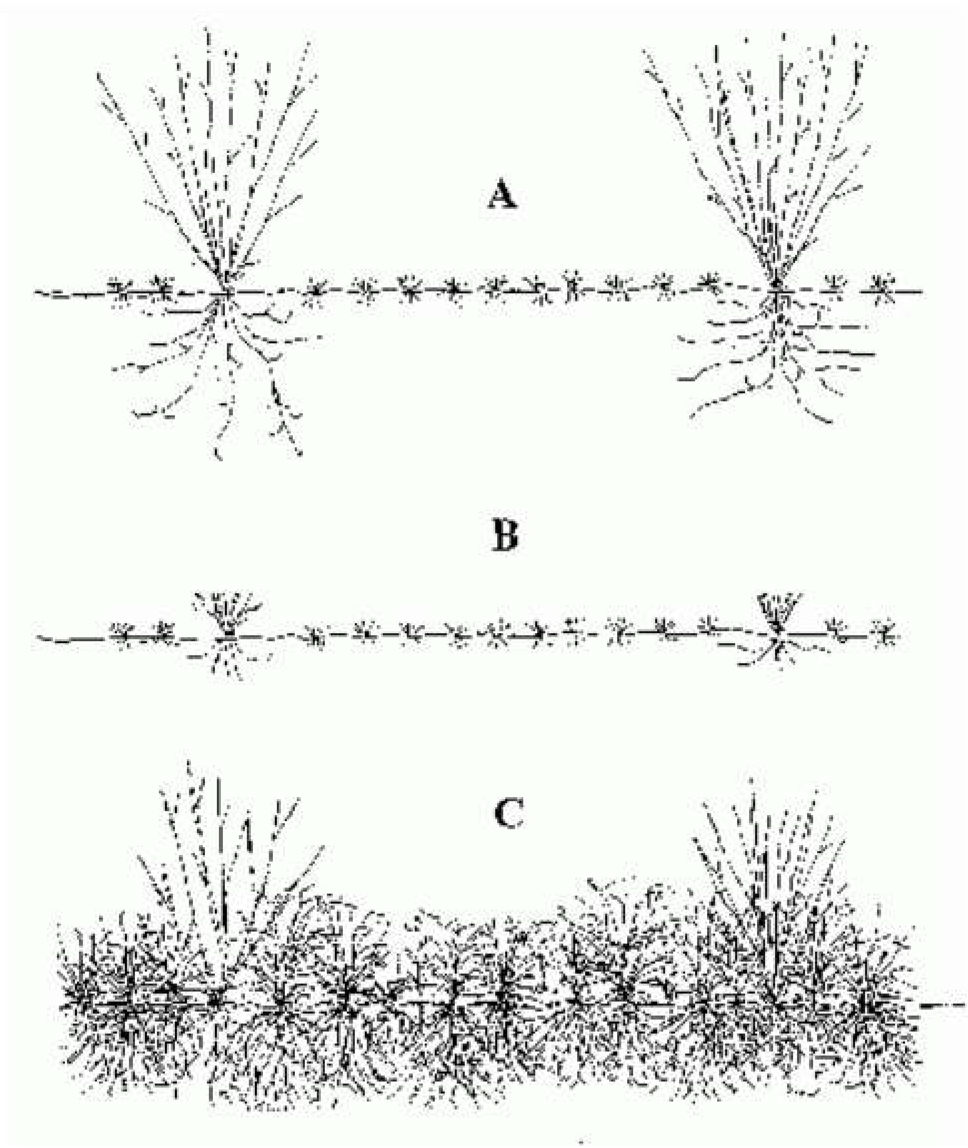

Figure 2. Effects of grazing on the root systems & competitive interactions between plant species

A) *A reduction in the size and depth of the root system after grazing. The less palatable species which are not grazed continue to develop a deep root system. The root system of more heavily grazed species is reduced.* ***B)*** *Where the sward is grazed evenly, as in many rotational grazing systems, the roots of all plants are reduced.* ***C)*** *During the long rest period all plants species can regrow deep complex root systems. (Taken from Jones (2000)).*

4.7. Summary of theoretical benefits

Table 1. provides a summary of the theoretical benefits of rotational grazing which have been detailed above.

Table 1. Theoretical benefits

Theoretical benefit	Benefit summary
Soil	• Greater soil carbon storage • Increase microbial activity • Increased soil nutrients • Higher soil organic matter • Better water holding capacity
Sward composition & forage quantity and quality	• Preferred plant species are maintained in the sward – leading to greater nutritive value of the forage • Plants develop deep root systems – leads to improved ability to uptake nutrients and water & greater resilience to drought • Sward remains productive for longer
Greenhouse gas emissions	• Reduced methane production from rotationally grazed animals as the result of improved vegetation quality and digestibility
Animal health and production	• Healthier animals • Diverse pastures act as natural de-wormers • The choice of appropriate breeds leads to productive livestock enterprises
Biodiversity	• Opportunity for plants to flower – leads to increased pollinators & seed source to maintain pasture • Non-selective grazing- leads to species rich sward • Tall grass – Provides habitat for birds, insects, and voles. These can support species at higher trophic levels i.e., owls feeding on voles
Economics	• Extended grazing period reduces the need for straw and winter feed production/purchasing • Improved sward persistence reduces the need for re-seeding

5. Evidence for theoretical benefits

Having outlined the theoretical benefits in the previous section, we now assess what evidence there is for these anticipated benefits of rotational grazing. Evidence relating to soil conditions, forage quality, greenhouse gas emissions, animal health, biodiversity, and economics are all considered in turn. Supporting details of the studies which address each of these aspects and, where applicable, the grazing regimes being compared is included in a separated spreadsheet (available on request).

5.1. Soil

5.1.1. Soil Carbon

Soil carbon concentrations have generally been found to increase under rotational grazing systems, but this is often confined to the upper soil levels (Contosta et al., 2021, Wang et al., 2015, Conant et al., 2003). There was also a trend for soil carbon concentrations to increase over time in some studies, but this was seen to plateau 6 years after implementing a rotational grazing regime (Stanley et al., 2018, Machmuller et al., 2015). Two studies comparing continuous grazing with a rotational system found no difference in soil carbon concentrations (Shrestha et al., 2020, Orgill et al., 2018). However, the continuous grazing regime used by Orgill et al. (2018) had biannual rest periods and therefore cannot be classed as truly continuous (Orgill et al., 2018).

Other studies compared specific rotational grazing systems but with no consistent findings, as follows. A comparison between 'regenerative rotational grazing' and 'conventional rotational grazing', which differed in the length of the grazing and rest periods, showed higher soil carbon concentrations under the grazing regime with the shortest grazing period and longest rest period (de Otalora et al., 2021). However, two other comparative studies between different types of rotational grazing systems found no differences between them but details of the rest periods were not provided (Chamane, 2018, Russell et al., 2013). Furthermore, given soil heterogeneity, any changes may be difficult to detect.

5.1.2. Soil Nitrogen

No conclusive evidence was found for increases in soil nitrogen concentrations under rotational grazing, but comparisons between rotational grazing and true continuous grazing were limited. Some studies found an increase (Conant et al., 2003, Contosta et al., 2021) while others reported no difference (Orgill et al., 2018, Shrestha et al., 2020). Where comparisons were made between specific rotational grazing regimes, no differences in nitrogen concentrations were found (Chamane, 2018, Ferguson et al., 2013, Russell et al., 2013).

5.1.3. Other soil properties

Studies that measured other soil properties were too few to draw generalised conclusions. Examples include a study that found a lower carbon to nitrogen ratio when comparing rotational grazing with continuous grazing (Contosta et al., 2021). One where no differences were found in pH, moisture content or soil bulk density (Shrestha et al., 2020), and one where there was no difference in soil compaction, soil chemistry, pH, phosphorous, organic matter or CEC (Ferguson et al., 2013). Similarly, no differences were found in phosphorus, pH or water infiltration when considering differences between specific types of rotational grazing (Chamane, 2018, Russell et al., 2013). However, CEC and water holding capacity increased when converting from row cropping to MIG (Machmuller et al., 2015). Only Chamane (2018) showed more soil compaction under high density short duration stocking compared to a lower stocked system. Presumably this was a result of increased trampling by livestock.

Observations by Tom Chapman, a Hertfordshire farmer, indicate higher levels of organic matter in rotationally grazed fields ("mob grazed") compared to those under continuous grazing (Chapman, 2021). Andrew and Robert Brewster from Easter Denoon farm in Angus have anecdotal evidence that rotational grazing ("mob grazing") builds more soil fertility (Brewster and Brewster, 2021).

5.2. Sward composition & forage quantity and quality

5.2.1. Forage Quality & Biomass

Forage quality and forage biomass are important for both animal health and the economic success of livestock enterprises. There have been few studies which focus on these, with most studies having reported little difference between various forms of rotational grazing or between continuous and rotational grazing (Tracy and Bauer, 2019, Bauer, 2015, Russell et al., 2013).

It should be recognised, however, that the nutritional value of the sward may not be mirrored directly by the nutritional value of the forage consumed. For example, Bauer (2015) reported that cattle grazed under a mob system took in a less nutritious diet than those grazed under a less intensive rotational system and a continuously grazed system, despite vegetation clippings from all grazing treatments having a similar quality. This was attributed to the paddock being subjected to rapid defoliation and trampling, thus limiting the opportunity for the animals to select the most nutritious vegetation.

Biomass production differed between studies, with no consistent findings. Spring grass production was higher under an intense rotational system (short grazing period and longer rest period) in one study (de Otalora et al., 2021), while a less intense system (longer grazing period and shorter rest) had higher pre-grazing forage biomass (Billman et al., 2020).

5.2.2. Fibre

Fibre content also differed between studies with no consistent findings. One study found higher forage fibre content under a mob grazing system, presumably due to the more mature vegetation (Billman et al., 2020). Yet this finding was contrary to Heitschmidt et al. (1987). They found higher organic matter digestibility and crude protein under the rotational systems. The higher stocking rate in the rotational grazed paddocks was thought to prevent the build-up of dead vegetation in the sward. This highlights the difficulty in teasing apart the stocking rate and the grazing method as they can both interact (Bauer, 2015).

5.2.3. Root system

Much of the rationale for mob grazing lies on the premise that allowing the pasture time to rest and grow tall enables the development of a deep, complex root system. We found no evidence in the literature for this, with no studies reporting investigations of root depth and structure in relation to real-life rotational grazing systems. However, some farmers using more intensive forms of rotational grazing (“mob grazing”) have reported that they can ‘see’ the benefits of deep rooted grasses (Soil Association Scotland, 2021); and observations that forage is of higher quality on rotationally grazed pastures compared to those continuously grazed after drought periods is often attributed to a deeper root system (Bauer, 2015).

5.2.4. Plant species composition

Evidence to suggest that less-desirable plant species are kept in check by rotational grazing is mixed. Less palatable species have declined under rotational grazing in some situations (Earl and Jones, 1996, Chapman, 2019). A smaller amount of bare soil has also been recorded in one study under mob stocking compared to continuous or lower intensity rotational systems and, where this occurs, it may prevent weeds from establishing (Bauer, 2015). Yet others found no effect of rotational grazing on weed cover (Tracy and Bauer, 2019) and where rotational regimes of different intensities were compared, less palatable species were more common under the high density, short duration stocking compared to a lower density rotational grazing system (Chamane, 2018).

5.2.5. Grazing season

There appears to be no empirical evidence that rotational grazing extends the grazing season but anecdotal evidence provided by farmers suggests that this is the case (Soil Association Scotland, 2018, Chapman, 2021).

5.3. Greenhouse gas emissions

Many of the studies which consider greenhouse gas emissions are based on models, which means the validity of the assumptions is highly dependent on the data included in the models. Models have shown that greenhouse gas emissions should be lower using rotational grazing systems rather than continuous grazing (Wang et al., 2015, Stanley et al., 2018). Empirical studies have also shown lower methane production in some situations which has been attributed to sowing grass species well suited to animal production under rotational grazing (DeRamus et al., 2003). However, this is not always the case. Rotational grazing can lead to an increase in N_2O emissions, probably as a result of large concentrations of dung being deposited on the pasture (Contosta et al., 2021). Furthermore, it has been shown that moisture and temperature interact with the grazing regime to influence how much CO_2 is emitted. Rotational grazing has been shown to emit more CO_2 than continuous grazing under cool conditions but less CO_2 at higher temperatures (Shrestha et al., 2020).

5.4. Animal health and production

Anecdotal evidence from farmers identifying as mob graziers suggests that this form of rotational grazing leads to healthier animals (Chapman, 2021, Fir Farm, 2021, Hanson et al., 2013). However, results were variable with no consistent findings overall; also, many studies focused on animal body weight or milk production as a measure for the successfulness of the grazing regime rather than 'health', which is a measurement of the state of illness or injury of an animal. Lower cow weights going into the winter were recorded under a mob grazing system relative to a lower intensity rotational system and continuous grazing (Tracy and Bauer, 2019). Similar results were found for sheep (Oliva et al., 2021). An intensive rotational system was also seen to result in lower cow body weights when compared to a confinement feeding system (Fredeen et al., 2013). However, another study which compared three different rotational regimes found no differences in cow body weights (Russell et al., 2013).

When considering milk production, fat and crude protein levels were lower in milk produced using an intense rotational system rather than confinement feeding (Fredeen et al., 2002). However, in terms of overall production levels some studies have shown milk yields to be higher under intense rotational systems while others have found the opposite to be true (Fredeen et al., 2013, Hanson et al., 2013).

5.5. Biodiversity

Few of the studies found in the literature examined the effect of rotational grazing on wider measures of biodiversity, and much of the evidence found was anecdotal. Some studies estimating changes in soil properties considered soil micro-biodiversity, and others as discussed above assessed plant species diversity within the pasture. Andrew and Robert Brewster observed more bird life on their farm, particularly more curlews where taller grass was left during the nesting season (Brewster and Brewster, 2021). Rob Havard from Phepson farm, Worcestershire also reported benefits to wildlife including an increase in voles utilising the taller grass, which in turn led to an increase in owls and kestrels which feed upon them; they also reported an increase in insects (Soil Association Scotland, 2018, Triodos Bank, 2021).

5.6. Economics

As with the other theoretical benefits, evidence for economic benefits is also mixed. Reported benefits include the following. Phillip et al. (2001) reported that rotational grazing systems with a high stocking rate generated higher net revenue than continuous grazing systems despite the animals performing slightly worse. Similar results were found when using an intensive rotational grazing system instead of confinement feeding for dairy cattle. Less milk was produced under MIG but the enterprise was no less profitable than confinement feeding due to reduced costs (Hanson et al., 2013). It has also been noted that less time is required to check on rotationally grazed animals (time = money), resulting in obvious health issues being more quickly identified when moving the animals to fresh grazing, with resultant reports of lower veterinary bills since switching to rotational grazing systems (Chapman, 2021, Fir Farm, 2021, Hanson et al., 2013).

Reported disbenefits include the following. In one study, mob grazing gave the lowest mean net return on costs associated with the grazing regime when compared to another less intense rotational system and a continuous grazing regime (Janssen et al., 2015). Initial outlays for rotational grazing include the purchase and installation of electric fencing and the provision of additional drinking water sites if the position of paddocks means the animals do not have access to natural water sources (Chapman, 2021). Further investments may also need to be made such as re-seeding pastures with species better suited to rotational grazing and a move towards smaller or traditional livestock breeds which may fare better under rotational grazing systems. However, opinions on the need for these investments are variable (Koster, 2017, Chapman, 2019, Casler et al., 1998, Billman et al., 2020). For this reason, any assessment of the economic viability of a rotational grazing system should consider a longer-term perspective.

6. Conclusions

6.1. Terminology

Our disentangling of the terms used to describe rotational grazing revealed that it is generally inappropriate to compare studies based purely on a named grazing regime because of the wide range of definitions used and the apparent overlap and inconsistences in the use of individual terms. Probably the most feasible way to compare studies is to consider the intensity of the rotational regime based on the length of the grazing period, rest period (and/or sward height-based decisions). However, this information is not always quoted in individual studies, making comparisons of their findings extremely difficult. Furthermore, even when the information is present, individual differences in multiple variables, such as the number of animals, paddock size and length of grazing or rest period make it incredibly difficult to compare like with like across studies. For this reason, we conclude that it is not possible to simply compare ‘rotational grazing’ with ‘set stocking’, ‘confinement feeding’ or another alternative use of agricultural land.

6.2. Did the evidence support the theoretical benefits of rotational grazing?

Support for the theoretical benefits of rotational grazing was weak or absent in many cases. When considering **soils**, rotational grazing, particularly with a long rest period, generally enhanced soil carbon storage in the few studies that we found. Where this was not the case, we consider that the two grazing regimes being compared were likely too similar. Evidence for changes in other soil properties was even less conclusive. It is important to bear in mind that the soil type and the grassland species composition, as well as the previous management history, are all likely to influence the potential for rotational grazing to alter soil properties and processes.

Empirical studies which measured the **root systems** of plants were lacking. As the development of deep, complex root systems are thought to be one of the key benefits of implementing intense rotational grazing, this is certainly an area for further research. There were mixed reports on **plant species composition** under rotational grazing, and no consistent recorded impacts on forage biomass production and vegetation quality. The differences between studies are likely to be dependent on the species composition of the sward and annual variability in weather conditions (Tracy and Bauer, 2019). Choosing species mixes that are best suited to rotational grazing systems is likely to achieve better results (Casler et al., 1998, Billman et al., 2020) but again there is currently a lack of evidence to support this.

Ruminant livestock are known to be a major contributor to **greenhouse gas emissions**, and intensive rotational grazing is thought to be a way to reduce and mitigate these effects, but once again evidence to support this was sparse. Support for improvements in **animal health** was also weak due to lack of studies rather than contradictory evidence. However, when assessing the **economics** of rotational systems, it has been recognised that veterinary costs can be lower. But, when assessing economics more widely, the reported financial benefits of rotational grazing were mixed and showed variation between rotational grazing systems, again with no consistent findings from which to generalise. Support for enhancements in **biodiversity** as a result of rotational grazing systems was only anecdotal.

6.3. Is one rotational system better than any other?

There was no consistent evidence with which to assess whether one system might be better than any other for any of the headline theoretical impacts. Factors contributing to this lack of evidence of course include (a) a wide variety of differing rotational systems which often have limited replication across studies and (b) a wide geographical spread of studies with differences in grassland types, climates, and soils at each of the study sites. There was an indication that the length of the rest period may be influential in whether or not any of the theoretical benefits of rotational grazing are achieved (de Otalora et al., 2021). There was also weak evidence that more intense rotational grazing may be better than less intense rotational systems or set stocking, but this requires more research. It should be noted that all empirical studies found, that compared different rotational grazing systems were conducted in systems which were very different to the UK. To date, in the published literature we found that support for the benefits of rotational grazing from a UK perspective is still largely anecdotal, from farmers practising the technique. There is an urgent need for more associated experimental research.

Rotational grazing, particularly the more intensive forms, is certainly of interest due to the perceived benefits. Now would be a pertinent time to develop robust, replicated rotational grazing experiments in the UK, to see if these benefits can be realised here. This will not be a straight-forward task as assessing a range of grazing and rest periods alongside a variety of stocking densities and pasture species mixes will require substantial resources. However, as we urgently seek to address net-zero targets and develop climate-positive farming systems, it will be valuable to better understand the role that rotational grazing systems may have.

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Appendix 1.

Definitions of the wide range of rotational grazing regimes found in the literature

Adaptive Multi-Paddock grazing - "AMP grazing is a values-based triple bottom line approach (social, environmental and economic sustainability) to decision-making in grasslands that builds on a high-intensity, short-duration grazing to allow adequate recovery of grazed plants within a proactive, flexible, and goal-directed plan" (Hodbod et al., 2016).

Adaptive multi-paddock (MP) grazing - "is an advanced, more effective form of rotational grazing in which cattle are stocked to match forage amounts, and management is adjusted to: (1) reduce runoff, and losses of soil, nutrients, pathogens and other biological materials from grazed lands, (2) provide more forage and greater net economic returns, (3) conserve natural resources, and (4) enhance ecosystem function and resilience by maintaining sufficient residual litter (Teague et al., 2013; Wang et al., 2016) cited in (Park et al., 2017a).

Adaptive MP grazing - "involves rotating livestock among multiple paddocks to distribute grazing pressure over the whole landscape of the ranch, better control grazing amounts, and ensure adequate recovery of grasses after grazing in the paddocks. During periods of low productivity, animal numbers under adaptive MP grazing are adjusted down to match available forage, and supplementary feeding is provided only to correct for forage quality, not quantity. If managed effectively, adaptive MP grazing can improve the range resource, and thus carrying capacity and profitability"(Park et al., 2017b).

Adaptive multi-paddock (AMP) grazing - "a form of rotational grazing in which small paddocks are grazed with high densities of livestock for short periods, with long recovery periods prior to regrazing" (Shrestha et al., 2020).

AMP – "applies an adaptive strategy that incorporates short grazing intervals with relatively high animal stocking densities, which are designed to allow plant recovery, promoting optimal plant communities and protecting soils (Conant et al., 2003; Teague and Barnes, 2017)" cited in (Stanley et al., 2018).

Cell (or time-controlled) grazing - "A form of intensive rotational grazing where many relatively small paddocks enable a short grazing period at heavy stocking rates, followed by a long recovery period" (Allen et al., 2011).

Cell grazing - "is sometimes confused with rotational grazing, it represents very different approach both practically and philosophically. It is based upon 'time control' pasture management, which requires the following practices: monitoring the rate of growth of pastures and resting (or spelling) pastures to allow for the regeneration of grasses and herbage; calculating stocking rates to match the carrying capacity of the pasture; planning, monitoring and managing the whole system very closely; utilising short grazing periods to increase animal performance; stocking cells at maximum density for short periods; encouraging a diversity of animals and plants to improve ecological health; and ensuring that there are large cattle numbers to encourage 'herding' behaviour (McCosker, 2000, p. 208) cited in (Richards and Lawrence, 2009).

Cell grazing – a high-level, time-controlled grazing method which follows the following principles: 1) Control rest to suit growth rate of plant; 2. Adjust stocking rate to match carrying capacity; 3. Plan, monitor and manage the grazing; 4. Use short graze periods to increase animal performance; 5. Use short graze periods to increase animal performance; 5. Use maximum stock density for the minimum time; 6. Use diversity of plants and animals to improve ecological health; and 7. Use large mob size to encourage herding (McCosker, 2000).

Holistic grazing – "uses short high-intensity grazing periods combined with long rest intervals" (Oliva et al., 2021).

Holistic grazing management – "… emphasizes intensive rotational grazing in which livestock density is increased and animals are moved frequently through different grazing areas (Briske et al., 2008) cited in (Garbach et al., 2017).

Management-intensive grazing (MIG) – "controls grazing frequency and intensity by moving livestock through as many paddocks as necessary, to regrow the forage on previously used paddocks" Murphy 2008 cited in Alvez et al. (2014). "Forage management must allow recovery periods between grazings that are long enough to restore forage to an optimum height [and] occupation periods must be short enough so that forage regrowth is not re-grazed" (Alvez et al., 2014).

Management-intensive grazing (MIG) - "… offers the potential for more efficient utilization of grazed forage crops via controlled rotational grazing and more efficient conversion of forage into meat and milk" (DeRamus et al., 2003). In their study DeRamus et al. (2003) had twenty-four paddocks of approximately 0.5 ha each with a stocking density of 50 to 60 animal units per ha per day. Recovery time of 15 to 30 d between each grazing period produced 1000 to 2000 kg of DM forage per ha. This maintained forage with at least 500 kg of DM per ha in each grazed paddock.

Management intensive grazing (MIG) – "is a practice in which large numbers of livestock graze within a small pasture for a short period (~24 h) before moving onto the next paddock. Also known as multipaddock grazing or intensive rotational grazing" (Contosta et al., 2021).

MIG – In Casler et al. (1998) the "Forage in each paddock was defoliated to a canopy height of 4 to 6 in. in less than 1 d, and the plants in each paddock were allowed to recover to a canopy height of 8 to 12 in. prior to the next grazing event… Rest periods ranged from about 20 to 40 d and generally were longest during summer. There were five or six grazing events on each farm during 1991 and 1992… This prevented the production of elongated stems and reproductive growth".

Management intensive grazing (MIG) – "a system of pasture management that utilizes rotational stocking with short grazing periods" (Phillip et al., 2001).

Management-intensive grazing – "[Is] characterized by a short period of intensive grazing by many animals on a small paddock and then a rotation to another paddock, usually after each milking or daily. Animals do not return to the first paddock until the grass has fully recovered, usually in 3 to 6 wk, depending on time of the season, weather conditions, and rotational system" (Hanson et al., 2013).

Management-intensive grazing – "Typically management-intensive grazing strives for grazing periods shorter than 5 days with rest periods of 20 – 40 days depending on plant growth rates. The idea is to keep plants in phase 2 or actively growing (vegetative to early reproductive)" (Kennedy, 2011).

Management-intensive grazing (MIG) – "a production system in which animals are rotated rapidly through a series of paddocks in order to maximise livestock production on either a per hectare or per animals basis" (Stout et al., 2000)

Mob stocking – "is a variation of rotational stocking known for restricting a large number of animals to a small area before being moved to new grass after a few hours. This method allows a long (90-day) recovery period" (Bauer, 2015)

Mob stocking (n.) - "A method of stocking at a high grazing pressure for a short time to remove forage rapidly as a management strategy" (Allen et al., 2011) .

Mob stocking - "grazing of plots with animals in 1 or 2 d" (Belanger et al., 2020)

Mob grazing – "uses very high stocking densities for short durations followed by a relatively long rest period" (Billman et al., 2020). In this study Billman et al. (2020) grazed the paddocks after 70-90 days of growth, when the sward reached more than 50cm in height. The paddocks were each grazed twice during a 12-month period.

Mob-grazing - "Strategic grazing at high stocking densities for short periods of time followed by long rest periods" (Bisinger and Russell, 2013). In this study Bisinger and Russell (2013) moved the cattle 4 times a day with a back fence. 50% of the live forage was removed & there was a 35-day rest period.

Mob grazing - "also referred to as high-density grazing, high-intensity grazing, or mob stocking by practitioners, often results in some portion of the forage being refused because of its maturity or being trod on by livestock" Grasses are grazed at mature stages (Brink et al., 2013)

Mob-grazing - "uses very high stocking rates on a small parcel of land with animals often moved several times per day. In this system, the land receives a long rest period, sometimes as much as one year. The system attempts to mimic the large grazing herds that once roamed the Great Plains" (Janssen et al., 2015).

Mob grazing – Paddock stocked heavily to ensure a uniform and complete grazing within a few days (Bittman and McCartney, 1994) cited in (Pecetti et al., 2009). Pecetti et al. (2009) had four grazing cycles per year, at a stocking rate exceeding 50 heifers/ha (Chianina breed), with a mean duration of 5.2 days/cycle (range 3–7days) and resting periods between grazing cycles averaging about 25 days.

Mob-grazing or high density grazing – "Mob grazing is defined as "grazing by relatively large numbers of animals at a high stock density for a short period of time" (Allen, et al 1991)" cited in Kennedy (2011). "Grazing periods are 1 day or less based on site, time and management objectives. Rest periods tend to be longer than with conventional management-intensive grazing ranging from 30 days to 180 days. The longer rest periods are based on the premise that the plants will be more fully rested and have a deeper root system…The goal is to remove 60 – 70% of the top growth and trample the rest onto the soil surface. It is the increased amount of litter left on the soil surface, pruning of deeper root system through grazing and increased concentration of manure that should help increase organic matter and feed the micro-organisms in the soil" (Kennedy, 2011).

Mob-grazing – "The term "mob grazing" can be subjective and with time it has been defined differently in both research and practice. Mob grazing in this study utilized longer grazing periods, lower stock densities, higher grazing frequencies, and shorter recovery periods than what is desired in ultra-high stock density grazing" (Misar et al., 2015).

Mob stocking – “a type of livestock management method where high densities of animals are restricted to a small area of grassland for short periods of time (e.g., 12–24 hr.) before being moved to new forage” (Tracy and Bauer, 2019).

Non-selective stocking (n.) - “A method that uses high grazing pressures that increase the consumption of less-preferred forage species by grazing animals (cf. mob stocking)” (Allen et al., 2011).

Rotational grazing/Cell grazing - Hall et al. (2014) recognise that the distinction between these grazing methods is not clear cut and occurs on a continuum. “Rotation methods vary widely, from extensive rotations, where there are only a few more paddocks than there are herds and rest periods vary from weeks to months, to intensive rotations with typically 20–60 paddocks per herd and where grazing periods, from 1 to 3 days, are much shorter than the rest periods, which may be 30–90 days…The more intensive rotations are commonly referred to as cell systems” (Hall et al., 2014).

Rotational grazing - “A period of grazing is followed by a period of rest for the pasture. Depending on pasture growth, these grazing and rest periods may vary from days to months” (Allen et al., 2011).

Rotational stocking- “A method that utlilizes recurring periods of grazing and rest among three or more paddocks in a grazing management unit through-out the time when grazing is allowed” (Allen et al., 2011)

Ultra-high stocking density (UHSD) – “uses high stocking density (BW/units area; up to 560,000 kg/ha) to graze small areas of mature forage (Salatin, 2008) for short durations and is characterized with long forage recovery periods (25 to 150 d; Hancock, 2010; Lemus, 2011)” cited in Hafla et al. (2014). Hafla et al. (2014) recognise that the definition of UHSD sometimes known as mob or tall grazing is quite ambiguous. They asked farmers for their definitions. These are provided in the table below:

Table 5. Results of an ultra-high stocking density grazing (UHSD) field day survey asking participants for their definition of UHSD[1]

Farmer response
Large number of animals on fenced small paddock grazing down tall “stored” growing plants for short periods
A lot of cows on a small area for a short time
Cattle grazing headed grass on the verge of rank
Wait until grass is very tall, let cows eat the top 1/3 of plants and trample the rest of the plant to feed the soil
High-density, short-duration grazing
Group of cows moving from pasture to pasture devouring grass or plants growing in the field
Grazing cows at >100,000 kg/ha
7+ cm regrowth with a herd of 200+ animals with frequent moves
Grazing at a height that is close to high-quality dairy hay or haylage using very high stocking rates
Grazing grass past ideal maturity so there is lower quality but higher quantity
Grazing patterns to maximize pasture rotations and nutrition for well-balanced nutrition

[1]Field day attended by 20 farmers on June 11, 2013.

Interchangeable terms – “The term time controlled grazing is often used interchangeably with the ‘Savory Grazing Method’, short duration grazing, holistic resource management or cell grazing. While there are subtle differences in these systems, they all rely on moving large numbers of stock around the landscape based on time or pasture growth (Savory, 1983; Savory & Butterfield, 1988)” cited in (Orgill et al., 2018).

The following table is from (McCosker, 2000) **summarising grazing systems and methods**:

Table 1. A summary of grazing systems and methods.

System/ method	Common names and/or sub-methods	Definition	Comments
Continuous	– Continuous grazing – Set stocking	Plants are continuously exposed to animals.	At high stocking rate, it causes widespread overgrazing of plants, is drought- and erosion-prone, and has fluctuating animal performance due to variations in quantity and quality. At low stocking rate, it causes undergrazing in patches and overgrazing in the remainder. May lead to woody weed ingress and overuse of fire. Animal performance is high and relatively stable.
Rotational resting systems	– Spelling – Deferred rotation – Deferred grazing – Merrill system	One or two more paddocks than there are herds or flocks. Rest may vary from weeks to years.	May defer effects of overgrazing. Leads to undergrazing and can reduce animal performance. Common reasons for use include: burning, drought reserve, special animal needs, allowing plants to seed.
Rotational grazing systems	– Rotational grazing – High intensity, low frequency grazing (HILF) – Short duration grazing	3–7 paddocks per herd on fixed calendar-based moves.	There are many approaches using rest periods of 30–365 days. Suffers from lower animal production than continuous grazing in 43% of cases studied. Perpetuates patch grazing and consequent under- and overgrazing effects. Can slow degradation in about 50% of cases. Can be used only on sweet country due to the effects of a long rest period on quality.
Multi-camp rotational grazing systems	(a) High utilisation grazing (HUG) – Acocks/Howell system – Short duration grazing – Non-selective grazing – Crash grazing – Mob grazing (b) High performance grazing (HPG) – Controlled selective grazing	(a) HUG. > 7 paddocks/herd. Each paddock is severely grazed before moving to the next, generally on fixed calendar-based moves. (b) HPG. > 7 paddocks/herd. Each paddock is lightly grazed for a short period so that only the most palatable plants are grazed. Ungrazed undesirable plants eventually die out. Calendar-based moves.	(a) Will reverse land degradation. High stock density and long grazing periods can lead to high utilisation and good animal impact. Suffers from very low animal performance. Usually uneconomic due to low gross margin. (b) Will reverse land degradation. Designed to increase palatable species. Has a short graze period and high animal performance. Has low stocking rate and is hence more wasteful of rainfall and sunlight energy than HUG. Usually uneconomic due to reduced turnover.
Time-control grazing methods	(a) Production focus – Block grazing – Strip grazing – Rational grazing (Voisin) – High density, short duration grazing (b) Holistic focus – Savory grazing method (SGM) – Cell grazing – Controlled grazing – Management Intensive Grazing (MIG) – Planned grazing – Ultra-high density grazing	> 7 paddocks/herd, but usually 20–40. Moves are based on the growth rate of the pasture and its physiological requirement for rest. It is not calendar-based. Requires high stock density. (a) Production: Focus on maximising plant and animal production. (b) Holistic: Focus on ecosystem sustainability and optimising profit.	Recovery period is determined by plant growth rate. Paddock number and recovery period then determine graze period. Varying recovery period protects the plant. A short graze period maintains high animal performance. Combines the best features of D(a) and D(b). Makes more effective use of rainfall and sunlight energy than other approaches.