A PUZZLE OF GRAZING MANAGEMENT TOOLS IN THE INDUSTRIAL ENGINEERING KNOWLEDGE AREAS

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ABSTRACT

Animal feed is the biggest variable cost that a farmer must manage in cattle production. Thus farmers need to maximise profitability by increasing the amount of locally grown forage that is transformed into animal output. Grazing management must be viewed as a collection of dynamic decisions that lead the farm towards its production goals. This study explored the available literature on grazing management tools and technologies, and categorised them according to industrial engineering (IE) bodies of knowledge (BOK) tools and technologies. A systematic literature review was conducted to retrieve the relevant literature. It was found that, although the technologies to aid grazing management exist, models still need to be developed into a fully functioning decision support system. The findings from this study provide guidance for future research on how to develop the tools and models into decision support systems.

OPSOMMING

Veevoer is die grootste veranderlike koste wat 'n boer in beesproduksie moet bestuur. Boere moet dus winsgewendheid maksimeer deur die hoeveelheid plaaslik verboude voer wat in diereproduksie omskep word, te verhoog. Weidingsbestuur moet beskou word as 'n versameling dinamiese besluite wat die boerdery na sy produksiedoelwitte lei. Hierdie studie het die beskikbare literatuur oor weidingbestuursgereedskap en -tegnologie ondersoek en dit volgens bedryfsingenieurswese (IE) kennisliggame (BOK) gereedskap en tegnologieë gekategoriseer. 'n Sistematiese literatuuroorsig is uitgevoer om die relevante literatuur te herwin. Daar is gevind dat, alhoewel die tegnologieë om weidingsbestuur te help bestaan, modelle steeds ontwikkel moet word tot 'n ten volle funksionerende besluitsteunstelsel. Die bevindinge van hierdie studie verskaf leiding vir toekomstige navorsing oor hoe om die gereedskap en modelle in besluitondersteuningstelsels te ontwikkel.

1. INTRODUCTION

Sustainable beef production has been interpreted by the Global Roundtable for Sustainable Beef as a product that can be associated with the triple bottom line theory [1]. Therefore, the product must adhere to social, environmental, and economic criteria. To deliver a sustainable product that adheres to the triple bottom line, a farm should have a management strategy that gives guidance and sets objectives for the entire farm's production goals while being socially responsible, economically viable, and environmentally sound [2].

South Africa has about 50 000 large commercial family farmers and roughly 240 000 small-holder family farmers [3]. Small-holder family farmers in South Africa usually use more traditional management methods, practices, and technologies that have been passed down from previous generations [3]. In other words, many of these small-scale farmers in South Africa do not use modern business methods and management strategies to optimise their farm's production performance.

Animal feed is the biggest variable cost that a farmer must manage in cattle production [4]. Thus farmers need to maximise profitability by increasing the amount of locally grown forage that is transformed into animal output (meat or milk) [4]. Systems based on livestock grazing should deliver a significant amount of forage with a high nutritional value in the most effective and economical manner [4]. Planning grazing rotations and allocating pasture in accordance with the herd's fodder demand can be done through regular monitoring of herbage. Grazing management must be viewed as a collection of dynamic decisions that include the temporal and spatial variation of pasture growth, which are primarily related to weather, soil nutrients, and grazing management elements [4]. This strategy calls for appropriate methods and techniques to track variations in herbage constantly, which can be time-consuming and labour-intensive [4].

The management strategy should therefore use a stocking strategy for cattle (which includes stocking rates and stocking methods) to optimise a land's forage use and animal performance (Rouquette & Aiken, Chapter 5 - Managing grazing in forage - livestock systems, 2020). A stocking strategy is an approach that integrates stocking rates, stocking methods, nutritional qualities, and climatic circumstances to meet the farm's production goals [5]. The stocking rate is the number of animals per area over a specific time [5]. If stocking rates are kept too high over time, land degradation occurs, which leads to pastures having a lower yield [6]. The pasture will decline over time until grazing is not possible. This phenomenon is called overgrazing [6]. Farmers need to maintain a balance between grazing the pastures for cattle performance and overgrazing. Cattle performance differs according to the farm's goals: it can be, for example, the milk yield of the cows, the number of calves delivered per season, or the mass of beef delivered.

A stocking strategy that improves the use of pasture and animal performance leads managers to use a flexible grazing system (Rouquette & Aiken, Chapter 5 - Managing grazing in forage - livestock systems, 2020). Flexible grazing systems are used to adjust the stocking method and stocking rate on a visual-quantity basis (Rouquette & Aiken, Chapter 5 - Managing grazing in forage - livestock systems, 2020). There are numerous stocking methods, but the two main ones in livestock pasture management are 1) continuous stocking, and 2) rotational stocking [7]. Continuous stocking does not restrict cattle to one pasture, and provides uninterrupted access to that pasture [5]. Rotational stocking uses numerous pastures to allow a previously grazed pasture to rest while another is grazed [5]. Rotational stocking can be subdivided into other stocking methods, such as strip stocking, mob stocking, alternate stocking, seasonal stocking, or sequence stocking [8].

There are a handful of farmers in South Africa who have moved away from traditional stocking methods (such as seasonal stocking) to more modern methods such as strip stocking and mob stocking. These farmers state that they have noticed many benefits that go beyond just animal gain per hectare. They include:

- Being able to detect sick livestock sooner [9];
- Reduced wastage, as all forage is consumed by the livestock (and not just the juicy and greener polls) [10];
- Animals having fresh, uncontaminated pasture [10];
- Diseases are reduced as parasite lifecycles are broken [10];
- Livestock dung is spread more evenly throughout the pasture [10];
- Better use of pasture [11]; and
- Decreasing the potential for soil erosion [10].

However, there is no silver bullet for stocking methods. One method is not necessarily superior to another, as it depends on the farm's specific needs, situation, and goals. If a farmer uses the correct management and stocking strategy for the farm's specific needs, it could lead to an increase in the farm's performance.

If an industrial engineering perspective is used when looking at a farm, the farm itself can be likened to a factory, manufacturer, or organisation. The cattle are seen as the raw material, the grazing system as the process, and the beef/milk at the end of the production line as the finished product. If the production line is not working as it should, the quality of the finished product (meat/milk) will not be satisfactory. The amount of finished product will also not reach the intended production target. A puzzle could show where the different pieces of agriculture fit into industrial engineering concepts. This could help to identify where industrial engineering knowledge is yet to be applied to allow future studies to improve current grazing management tools and technologies.

This study aims to explore the available grazing management tools and technologies and to categorise them according to industrial engineering (IE) bodies of knowledge (BOK) tools or technologies. This would enable future research to have a starting point for knowing which technologies were available and what could be improved. This would provide farmers with adequate decision support for grazing management and cattle production. The categorisation of the tools according to the IE BOK tools would also indicate where industrial engineers could assist when providing farmers with decision support systems. As South Africa is a water-scarce country, cattle grazing management is of great importance. This literature review makes a good contribution to defining meaningful projects for the development of decision-support models to improve grazing management.

2. RESEARCH METHODOLOGY

To achieve the aim of this study, a systematic literature review (SLR) was conducted. To examine the scopes of multiple studies and the function of the designed frameworks in each study, the SLR took the shape of a scoping SLR [12]. The approach of Albliwi *et al.* [13] was the foundation for the SLR method used in this investigation. Figure 1 shows the order of the steps and how they were organised into phases. The specifics of each step are as follows:

- Step 1: Create a research purpose and/or objective – clearly explain the SLR's objective.
- Step 2: Develop a study protocol – the protocol should include the aim, inclusion criteria, exclusion criteria, databases, keywords, and quality assessment criteria.
- Step 3: Determine the criteria for relevance – explain why a resource is relevant to this study.
- Step 4: Find the literature by searching and retrieving it – use relevant scientific databases to find the literature.
- Step 5: Selection of studies – use the criteria developed in Step 3 to choose studies.
- Step 6: Quality assessment for applicable studies – evaluate each paper's quality.
- Step 7: Data extraction – gather the relevant data from the papers.
- Step 8: Analysis and synthesis of data – analyse and synthesise the data from the selected papers to reveal themes and patterns.
- Step 9: Report – summarise the findings of the review.
- Step 10: Dissemination – publication of the SLR.

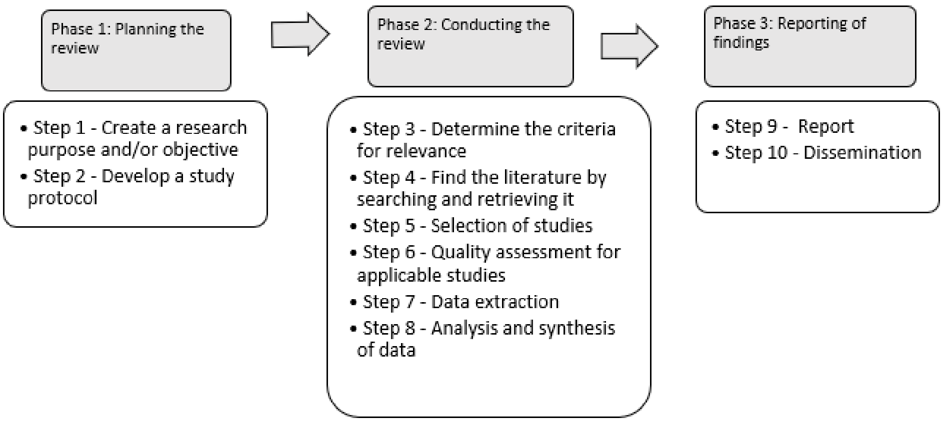

Figure 1: Research phases (adapted from [13])

The results of steps 1 to 6 are addressed in the subsections below, while steps 7 and 8 of the study's findings are detailed in section 3. Steps 9 and 10 are completed by publishing this study.

2.1. Step 1: Develop a research purpose and/or objective

The purpose of this research was to investigate the available grazing management tools and technologies to categorise them according to IE BOK tools or technologies.

2.2. Step 2: Develop research protocol

Table 1 shows the research procedure that was created. Scopus was chosen as the database from which the literature was retrieved, as Scopus is the largest abstract and citation database of peer-reviewed literature and covers most scientific fields [14]. The study protocol includes key phrases and quality assessment to give instructions on what to look for and how to judge the quality of papers. This study used multiple key word inputs (as shown in Table 1) that related to the purpose of the study in order to have a better overview and so conduct a thorough investigation.

2.3. Step 3: Establish relevance criteria

The relevance criteria need to be precise while also allowing for the inclusion of as many articles as possible [12] [13]. The relevance criteria started with only tools and technologies as the keywords, but were expanded to give a broader view of all grazing management tools and technologies. Table 1 captures the detailed breakdown of the inclusion and exclusion criteria. Papers were included if they contained the keywords in their title, abstract, or keywords of the study. Furthermore, literature was included if it used or explained prediction models, grazing management strategies, production goals/plans and/or linear regression models.

Studies were excluded if they were not in English, if articles focused on crop production, if they focused on anything other than the cattle's or pasture's condition (for example, various studies used grazing management as a tool while measuring the effect on butterflies), and when they were focused solely on pasture health and did not include cattle condition and production.

Table 1: Research review protocol

Protocol step	Protocol to follow
Purpose of the study	To explore available grazing management tools, strategies, methods, decision criteria, principles, theories, and technologies
Keywords	• "Grazing Management" AND "methods" AND (LIMIT-TO (EXACTKEYWORD, "Cattle") • "Grazing Management" AND "decision" AND (LIMIT-TO (EXACTKEYWORD, "Cattle") • "Grazing Management" AND "principles" AND (LIMIT-TO (EXACTKEYWORD, "Cattle") • "Grazing Management" AND "theories" AND (LIMIT-TO (EXACTKEYWORD, "Cattle") • "Grazing Management" AND "tools" AND (LIMIT-TO (EXACTKEYWORD, "Cattle") • "Grazing Management strategies" AND (LIMIT-TO (EXACTKEYWORD, "Cattle") • "Grazing Management technologies" AND (LIMIT-TO (EXACTKEYWORD, "Cattle")
Search databases	• Scopus
Inclusion criteria	• Literature in which any of the following are used or explained: o prediction models; o grazing management strategies; o production goals/plans; o linear regression models. • Literature that contains the keywords in the title, abstract, or keywords of the paper. • Literature that contains "cattle" as a keyword. • Literature that focuses on grazing management strategies and technologies.
Exclusion criteria	• Non-English literature. • Articles focused on crop production. • Literature in which the main focus was on other research and the cattle's or pasture's condition was a secondary effect (for example, studies using grazing management as a strategy while measuring the effect on butterflies). • When the literature is solely focused on pasture health and does not include cattle condition and production.

Protocol step	Protocol to follow
Quality assessment criteria	• Studies should be published in English • Repeatable and reputable scientific research methods should have been followed. • The studies should also adhere to the following quality checklist [15]: 1. The article clearly states its aims and objectives. 2. The article provides an outline of the scope, design, and context of the study. 3. The variables in the study are reasonable and reputable. 4. The article documents the research process sufficiently. 5. The article answers all of the study questions. 6. All of the negative findings are presented. 7. The main findings are stated and are verified as credible, valid, and reliable. 8. The conclusions are reliable and relate to the aim or purpose of the study.

2.4. Step 4: Search and retrieve the literature

The searching and retrieving of the literature were done by searching through Scopus. Initially the key words were searched without the inclusion of the keyword “cattle”, which resulted in 2 058 articles. The search was then narrowed down by including “cattle” as a keyword, which resulted in 332 articles. The retrieval differentiation is outlined in Table 2.

Table 2: Retrieved papers

“Grazing Management”		**Limit to cattle: AND (LIMIT-TO (EXACTKEYWORD, “Cattle")**
AND “Decision”	414	60
AND “tools”	429	68
AND “theories”	81	6
AND “Principles”	97	12
AND “methods”	854	149
“Grazing management strategies”	180	36
“Grazing management technolog*”	3	1
TOTAL:	**2058**	**332**

2.5. Step 5: Selection of studies

The study selection criteria are outlined in the search protocol (Table 1) and step 3. Duplicates and non-English literature were removed, which left 268 articles. The selection process included screening through all of the articles’ abstracts and evaluating whether they met the inclusion and exclusion criteria. Only 27 papers met the inclusion criteria. The immense reduction in articles from the initial search to inclusion was because some articles only focused on the management of the pastures and crop production, while others used grazing management as a strategy while measuring the effect of some experiments.

2.6. Step 6: Quality assessment for relevant studies

Following the screening process, the quality of the studies was evaluated by reading the full texts. The papers were evaluated by using the quality criteria shown in the search protocol (Table 1) used by Van Dinter *et al*. [15]. The search and retrieval process was documented in a selection process chart in Figure 2.

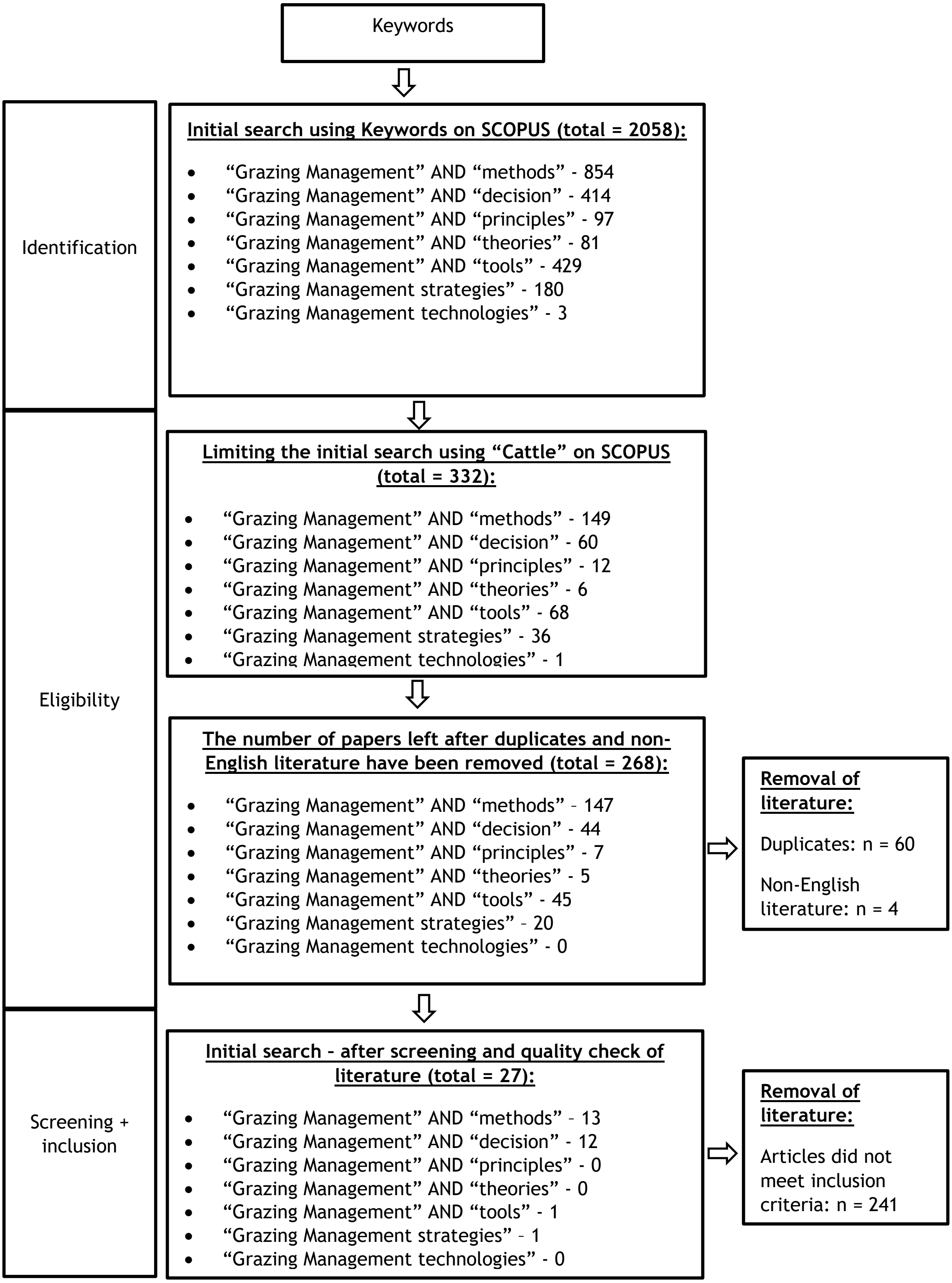

Figure 2: Selection process chart

3. FINDINGS

Step 7 (data extraction) from the SLR is presented in this section. After narrowing down the list of publications to be included and reading the complete texts, a summary was tabulated (see Appendix A). The summaries include the following key points presented in the papers:

- The article title, year of publication, and details of author(s).
- The technologies used or described in the paper.
- The tools used or described in the paper.
- The form of decision support that the technology provides.
- The strategies or methods used (specifically, what stocking method is used in the paper).
- The recommendations that could improve the decision support tool in the future.

4. DISCUSSION

Step 8 (analysis and synthesis of findings) is presented in this section.

4.1. Distribution of studies

The breakdown of the number of publications found per year group is shown in Figure 3. The search was not limited to specific years, but the data clearly shows that interest in the topic has increased considerably since 2005; 2022 produced the highest number of results – a testimony to the increased interest in the research topic in recent years.

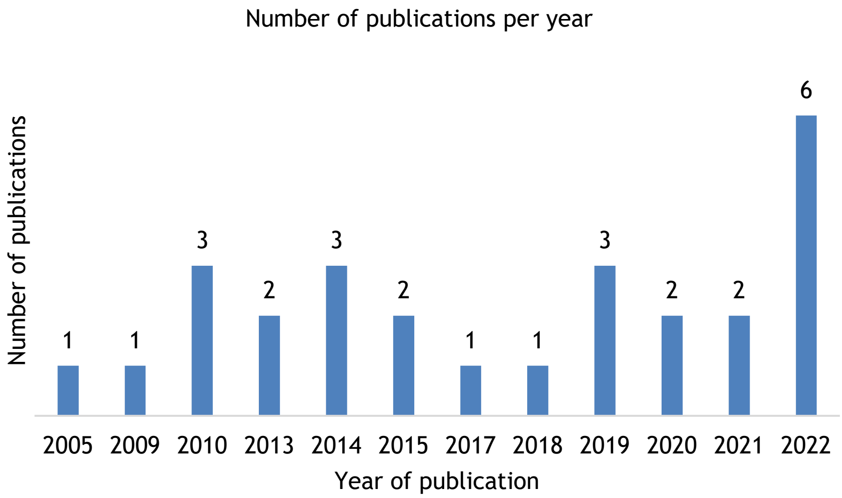

Figure 3: Bar graph of number of publications per year

4.2. Strategies or methods used in the studies

It is important to analyse the stocking methods used in the papers to discern which stocking methods already have had technologies and tools developed for them, and which do not. The stocking methods are illustrated in Figure 4. Both the continuous and the rotational stocking methods have been accounted for, and models have been developed that consider both methods, and even a combination of the methods.

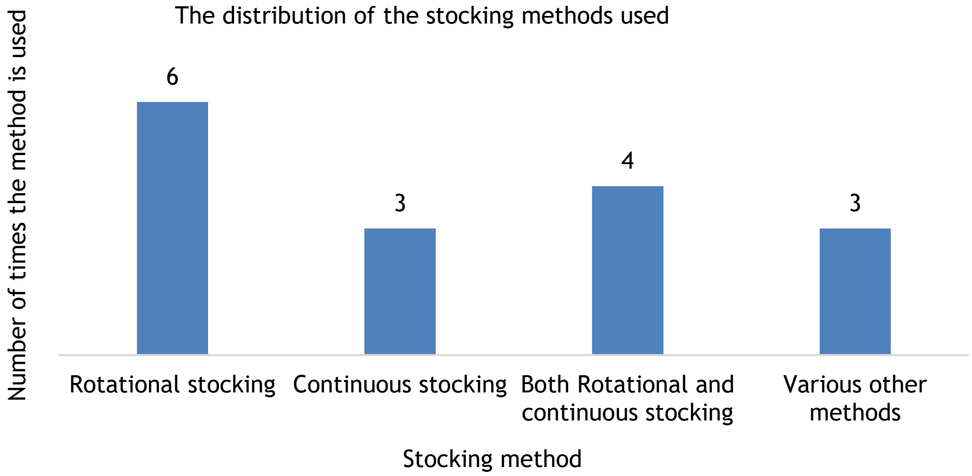

Figure 4: Bar graph of the distribution of stocking methods

Figure 4 reflects the following stocking methods:

- Rotational stocking – The tools and models used for rotational stocking are more complex, as there are more variables that need to be taken into account (e.g., there is more than one pasture). Even with rotational stocking having a higher level of complexity, this was still the most favoured stocking method.
- Continuous stocking – Continuous stocking has most of the same variables as rotational stocking, but it is only for one pasture, and usually supplementary feed is needed [16].

4.3. Technologies used or described in the papers

It is important to have sufficient and accurate data to analyse with the help of decision-support systems. The technologies used in the articles collect the relevant data, which is then analysed using the tools to support farmers or researchers with cow and pasture production.

The technologies used in the papers include:

Wearable sensors (such as collars and nose bands) that provide real-time data to the farmer (such as global position system coordinates, movement, behavioural characteristics);

R software to perform statistical analysis; and

Numerous grazing models (GrazeIn, MINDY, Agricultural Policy/Environmental eXtender).

4.4. Tools used or described in the papers

A variety of tools were used or explained in the papers. In this paper, 'tools' are seen as a method or technique to analyse raw data, not as instruments such as hammers or saws. The findings indicated that seventeen papers used some form of predictive modelling through simulations, linear regression models, or algorithms. Five papers conducted an economic analysis and six used statistical analysis to analyse the accuracy of the technologies and prediction models that were used.

The tools used can be categorised according to the areas in the institute of industrial and systems engineering body of knowledge (IISEBoK) [17]. Figure 5 illustrates the categorisation of the tools used according to the IISEBoK in a simple puzzle format. The predictive models using linear regression models and simulations can be categorised under 'operations research' and 'analysis' (knowledge area 2), as they are used as problem-solving tools that are focused on improving efficiency. The predictive models are used to improve real or theoretical systems by predicting the outcome of possible managerial changes.

The economic analysis tools can be categorised under 'engineering economic analysis' (knowledge area 3), which is used to understand the economic viability of any potential problem's solution. Economic analysis is done by setting up budgets and calculating the rate of return, taxes, and depreciation. The sales and purchases of cattle are considered against the pasture cost to maximise the asset value of the cattle and the economic returns.

The statistical analysis tools can be categorised under ‘quality and reliability engineering’ (knowledge area 5), which is used to measure the quality, accuracy, and reliability of the system. Basic statistics are used to compare the actual performance of the cattle and pastures with their predicted performance.

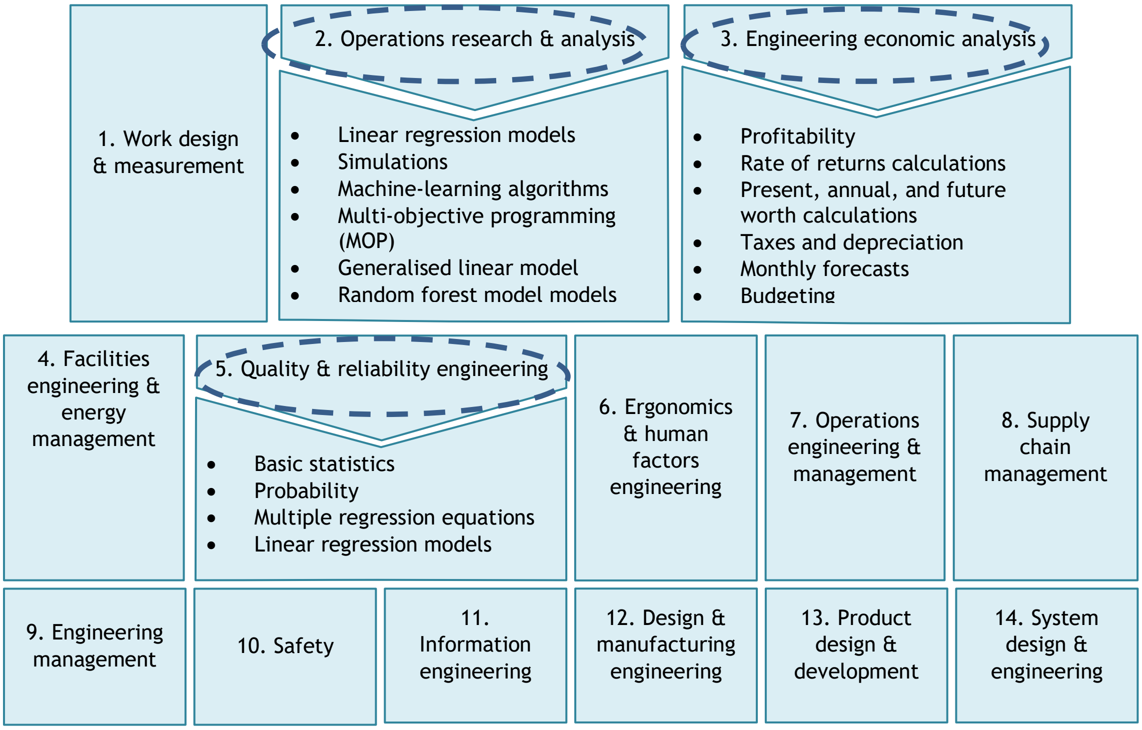

Figure 5: Knowledge areas of Industrial and systems engineering (adapted from the IISEBoK [17])

4.5. Future recommendations from the literature

Most of the papers had some form of recommendations for the future. There were six papers that stated that the models used should be expanded to accommodate other variables, or that they were suitable to be developed into a decision support system. In addition, two papers concluded that the model used was not applicable to farmers, and was more appropriate for researchers and experiments. Therefore, the models used have not yet been developed into a fully functioning decision support system.

5. CONCLUSION

This paper explored the available grazing management tools, strategies, methods, decision criteria, principles, theories, and technologies. A puzzle was drawn to show how the technologies and tools used in grazing management and industrial engineering concepts overlap. The aim was achieved by conducting a scoping systematic literature review, using the methodology adapted from Albliwi *et al.* [13]. Studies were selected on the basis of a review protocol. The findings of this review were tabulated and analysed.

It was found that technologies are available that aid in decision support for grazing management, and that these technologies should be used in combination with various tools. These tools include predictive modelling, economic analysis, and statistical analysis. The tools to be used were then categorised according to the IISEBoK’s areas (section 3.3). These tools use models that aim to help farmers to make more economically viable and sustainable decisions about cattle production and pasture growth. According to the outcomes of the selected literature review, six papers stated that the models were ready to be developed into a decision support system, but also needed to be expanded to accommodate other possible variables; and two papers stated that the models were not applicable to farmers. Therefore, although the technologies to aid in grazing management exist, the models still need to be developed into a fully functioning decision support system.

6. FUTURE RESEARCH

While this study focused on exploring the available literature on grazing management tools, strategies, methods, decision criteria, principles, theories and technologies, it is recommended that future studies explore how to develop the tools and models found in this study into fully functioning decision support systems. Future research should also improve the search strings used in this study in case any information might have been missed.

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APPENDIX

Num	Ref	Technologies used	Tools	Decision support	Strategies or methods used	Future recommendations
1	[18]	• Ruler • Measuring stick • Clipping with a frame • Plate meter • Capacitance meter • Leaf count		• Pasture height • Herbage allowance • Stocking rate • Stocking method	• Continuous grazing • Intermittent grazing • Rotational grazing	
2	[19]	• Solar-powered neck collars to measure GPS location at five-minute intervals. • Accelerometer to predict grazing activities every four seconds.		• Monitor foraging behaviour • Mean grazing bout duration • Cattle weight gain	• Continuous grazing	• The findings supply a pathway to equip cattle managers with daily updates of indicators of animal performance.
3	[20]	• Agricultural Policy/ Environmental eXtender (APEX) model	• Simulations • Prediction models • Economic analysis • Statistical analysis	• Algorithms • Input – Paddock area, grazing time, daily weight gain, vegetation biomass • Output – average annual cost, revenue, profits	• Planned rest-rotation grazing • Continuous grazing	• Some of the algorithms still need to be adjusted to consider all possible constraints. • The model overpredicts profits for continuous grazing system.
4	[21]	• Wireless accelerometer wearable sensors	• Predictive models • Machine-learning algorithms: ○ Generalised linear models (GLM) ○ Random forest (RF) ○ Artificial neural network (ANN))	• Total grazing time per day		The findings emphasise the necessity of employing managerial skills to develop a validation process that is more in line with the intended use of the prediction model, or with real-life situations.
5	[4]	• Unmanned aerial vehicle (UAV)	• Modelling – systems approach to land use sustainability (SALUS) – predicts pasture regrowth		Rotational grazing	Future technical development must concentrate on the automation of UAV data processing and mapping, as well as pasture modelling stages to enable

Num	Ref	Technologies used	Tools	Decision support	Strategies or methods used	Future recommendations
			• Morphogenetic and digestibility of pasture (MDP) – predicts leaf morphogenesis and forage nutritive value • Real-time data			rapid output data that can be provided in real time.
6	[22]		• Noy-Meir's predictive grazing model.		• Continuous grazing • Split-paddock grazing	
7	[23]	• JMP Pro 13.0.0 • R statistical software	• Simulations • Statistical analysis			
8	[24]	• Collar-mounted accelerometer, acoustic sensor, magnetometer, GPS	• Electronic rising plate meters • Behaviour classification model	• Pasture height		Intake algorithms need to be developed, to determine specific pasture intake behaviours.
9	[25]		• Prediction model to predict cattle activities throughout the day to varying quantities of available forage.	• Cattle bodyweight • Lying and grazing activity • Fodder shortages	• Continuous grazing	Using time-of-day-related changes in activity to identify minor fodder shortages may not be a feasible approach.
10	[26]	• ANOVA • R Software	• Linear modelling	• The effect of different systems on productivity and biodiversity of pasture was predicted.		In comparison with sheep-only systems, mixed highland grazing systems with cattle grazing increased animal productivity and decreased methane emissions.
11	[27]	• MINDY • ACSLXtreme	• Mechanistic and dynamic simulation model	• Reproduces the observed patterns of meals • Simulate realistic daily herbage intake	• Rotational grazing	MINDY can be used to design and organise experimental programmes.
12	[28]		• Predictive modelling			Create grazing predictions using mechanistic models, along with empirical feedback techniques and real-time data.
13	[6]	• LINDO (Linear, INteractive, Discrete Optimizer)	• Linear programming model • Multi-objective programming (MOP) models • Economic analysis	• Sales and purchases of cattle • Cattle stocks and the pasture costs • Maximisation of the asset value of cattle and maximisation of economic returns		Overall, the model's findings suggest that, depending on the situation, a certain amount of overgrazing may be justified. The resulting database ought to provide a more thorough approach to the issue of pasture deterioration and yield more useful data for controlling pasture decision-making. Farmers must also be provided with a variety of recovery techniques and maintenance procedures so that they can select the one that best suits their capital and natural resource endowments.
14	[29]	• ANOVA	• Economic analysis – profitability of each grazing system	• Meteorological data • Time at pasture • Treading damage • Pasture production, utilisation, and	• Strip-grazing (rotational stocking)	Lower profit was obtained when running a grazing system with reduced treading damage risk (control).

Num	Ref	Technologies used	Tools	Decision support	Strategies or methods used	Future recommendations
			• Statistical analysis	nutritive value of the sward • Feed intake and milk production. • Analyses whether keeping cattle indoors in the rainy season and feeding them silage would yield higher production and cause less treading damage		
15	[30]	• Agricultural Policy/Environmental eXtender (APEX) model	• Simulations • Prediction models • Statistical analysis	• Inputs: Dry matter intake, total digestible nutrients, and temporal distribution • Simulates the effect different management techniques has on cattle weight gain	• Continuous grazing • Intensive rotational grazing	
16	[31]	• Noseband sensor • Pedometers • RumiWatch Converter software • R software • Rising plate meter	• Generalised linear model • Random forest model	• Inputs: herbage mass, compressed sward height • Predicts herbage scarcity on the basis of behavioural changes		Rumination chews per day and bite frequency are both confirmed to be significant factors.
17	[32]	• Molly cow model • R Studio	• Predictive modelling • Statistical analysis	• Predicts ruminal fermentation, nutrient digestion, and performance of dairy cows		
18	[33]	• MooMonitor+ (accelerometer and GPS collar band) • RumiWatch noseband sensor • R Studio • Rising plate meter	• Statistical analysis • Correlation coefficient	• Measures the cattle behaviour and calculates the grazing time	• Continuous grazing	For researchers, the amount and quality of data detail should be quite high; however, farmers do not need the same level of data detail. Regarding the implementation on farms, the key goal should be a precise and unique use of the sensor, summarising processed information with set action points by the decision support tool.
19	[34]	• Pasture-based herd dynamic milk (PBHDM) model • plate meter	• Predictive modelling • Simulations	• Pre-grazing height • Post-grazing height • Simulates the intake and performance of dairy cattle • Aids in decision-making regarding the stocking rate, pre-grazing height, post-grazing height, and concentrate supplementation.	• Rotational grazing	The PBHDM model was created to serve as the framework for a potential decision assistance tool in addition to being beneficial at the research level.
20	[35]		• Simulations of long-term changes in ecological conditions and profit • Predictive modelling • Economic analysis		• Rotational grazing	The simulation findings show that economic conditions and profitability may be kept at 100% of maximum levels with management that aims to maintain economic conditions and variable stocking.
21	[36]	• GrazeIn model	• Predictive modelling	• Predicts grass dry matter intake (GDMI) and milk yield (MY).	• Continuous grazing • Rotational grazing	

Num	Ref	Technologies used	Tools	Decision support	Strategies or methods used	Future recommendations
				• Cow variables: age, milk fat concentration, parity, week of lactation, potential peak milk yield, milk protein concentration, body weight, body condition score (BCS), week of conception, BCS at calving, and calf birth weight. • Sward variables: grass fill value, grass energy concentration, grass protein value. • Grazing management variables: pre-grazing herbage mass and daily herbage allowance. • Supplementation variables: quantity and nutritive value of supplementation offered.		
22	[16]		• Multiple regression equations • Predictions	• Predicts grass dry matter intake (GDMI), milk yield (MY) and milk fat and protein yield (MSY). • Animal variables: Peak MY, days in milk, body weight, body condition score (BCS), BCS at calving. • Other variables: Pre-grazing herbage mass, pre-grazing sward height, post-grazing sward height, grass organic matter digestibility, daily herbage allowance, grass NDF.		
23	[37]	• GrazeIn model	• Prediction model	• Predicting herbage intake for grazing dairy cows • Cow variables: parity, potential peak milk production, body weight, body condition score, age, stage of lactation and gestation. • Grass variables: daily herbage growth rate, crude protein, content and OM digestibility. • Grazing management variables: area of each paddock, daily time at pasture. • Supplementation variables: amount and nutritive value of each supplement	• Rotational stocking • Continuous stocking	

Num	Ref	Technologies used	Tools	Decision support	Strategies or methods used	Future recommendations
24	[38]	• GrazeIn model	• Prediction model	• Predicts herbage intake and milk production of grazing dairy cows	• Rotational stocking systems • Continuous stocking systems.	Expand the GrazeIn model to beef cattle, heifers, steers, sheep, goats, etc. The GrazeIn model is suitable to develop a decision support system.
25	[39]	• Windows application – Farmax Dairy Pro • Combination of Farmax and MOOSIM	• Decision support model • Short-term and long-term predictions	• Decision support model that determines the productivity and economic results of managerial actions using monthly forecasts of pasture growth, farm, and herd statistics. • Inputs: pasture growth rates, maintenance requirements, lactation, body energy reserves, growth and pregnancy requirements, breed, liveweight, age, etc.		
26	[40]	• Moderate-resolution imaging spectroradio-meter (MODIS) images	• Predictive modelling • Economic analysis	• The model can be used to test different management scenarios. • The model has three parts: 1. Soil water balance and vegetation growth model 2. Animal growth 3. Economics • Inputs: rainfall, parameters of soil and vegetation, biomass.		When combined with rainfall forecasts, the model can act as a warning system to help in grazing management. The optimal time to remove cattle from the pasture to maximise weight gain and profit is after the peak of the wet season.
27	[41]	• Satellite images • PastureBase Ireland • Grass wedge • Herb'aVenir • Pâtur'Plan	• Spring, mid-season, and autumn rotation planner • Grass wedge and autumn budget • Pasture-based milk production systems • Grass growth prediction model	• Feed budgets/feed quantity • Stocking rates matched to quantity of grass the farm can grow • Herbage availability • Body condition score • Weekly grass measurement	• Rotational grazing	Tools and technologies such as virtual fencing and the GrassHopper, cow sensors, and remote sensing will provide farmers with knowledge and assistance in allocating herbage for grazing within their production systems