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Mineral and vitamin supplementation on sheep farms: a survey of practices and farmer knowledge

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Abstract

Mineral and vitamin (MV) supplementation is a routine management practice in many pasture-based systems of prime lamb production. The aim of the current study was to establish the MV supplementation practices on Irish sheep farms and farmer's knowledge and opinions in relation to supplementation strategies and MV deficiencies. A survey, consisting of 22 questions, was administered to all farmers participating in the Teagasc National Farm Survey (NFS) in 2016 which had a sheep enterprise (n = 177). The Teagasc NFS is a stratified random sample of farms with each farm assigned a weighting factor so the results are representative of the national population of farms. Sixty-nine percent of respondents supplemented their flocks with MV in addition to concentrate feed. Twenty-two percent supplemented based on laboratory analysis results (soil, herbage, blood, or tissue analysis). Thirteen percent supplemented based on veterinary advice with only 30% of this advice based on laboratory analysis results. Sixty-five percent supplemented for reasons other than laboratory analysis or veterinary advice; mainly due to tradition and previous experience. The most common stages to supplement ewes were pregnancy (78%), lactation (61%), and pre-mating (50%). Fifty-one percent supplemented lambs post weaning. Mineral buckets (free access solidified molasses-based licks containing MV and in plastic containers) and drenching (oral dosing with MV containing liquid) were the most common methods of supplementing ewes and lambs, respectively. Generic MV products (containing multiple minerals and vitamins) were the most commonly used followed by cobalt only products. Ease of use/labor requirements and cost were the most important factors influencing choice of supplementation method. Forty-six percent rated their level of knowledge on mineral requirements of sheep as "limited or no education/knowledge". Supplementation with MV did not increase (P > 0.05) ewe productivity (number of lambs reared/ewe joined) or gross margin/ewe. It is concluded that most supplementation decisions in sheep production systems are undertaken in the absence of veterinary advice or laboratory results, therefore are not evidence based. Knowledge transfer activities need to be designed to communicate best practice as regards MV supplementation.

Key words: based systems, farmer opinion, supplementation strategies, trace minerals, veterinary

INTRODUCTION

Mineral and vitamin (MV) supplementation is a routine management practice in many sheep production systems worldwide, including those which have pasture-based systems of prime lamb production. Forages, both grazed and conserved can provide up to 95% of annual feed requirements of sheep in pasture-based systems (Keady and Hanrahan, 2007). The concentrations of minerals in Irish pasture is often inadequate and varies throughout the grazing season (Curran et al., 2014; Kavanagh et al., 2014; Keady et al., 2022). Consequently, MV supplementation is undertaken with the objective of maintaining animal health and performance (e.g. body weight gain, ewe reproductive performance). There is an evidence that some farmers may be over supplementing ruminant livestock with minerals (Kendall et al., 2015; Sinclair and Atkins, 2015). Excessive mineral supplementation increases production and labor costs and can compromise animal health. Environmental mineral excretion is also increased.

Survey analysis is a highly efficient method of accumulating large volumes of data rapidly and at relatively low cost (Kelley et al., 2003). The Teagasc National Farm Survey (NFS) has, since 1972, collected detailed data on farm activities, resources, farm gross output, input costs and income, as well as other socio-demographic data from a statistically representative random sample of Irish farms. The NFS on an annual basis conducts a supplementary survey that is used to collect additional information from NFS respondents, which can be combined with the wide set of socio-demographic and economic data collected as part of the core NFS survey. The information in the NFS supplementary survey is used to examine research questions of importance to Irish farming. The current NFS sample of approximately 900 farms represent a farming population of approximately 85,000 farms (Dillon et al., 2018). The NFS is part of the EU-wide Farm Accountancy Data Network (FADN) and the provision to FADN of detailed microeconomic data on Irish farms fulfils Ireland's statutory obligation to provide data on farm output, costs and income to the European Commission on an annual basis.

There is a paucity of information on sheep farmers' knowledge and opinions in relation to MV deficiencies and current MV supplementation practices on sheep farms. The

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collection of this information is vital to the development of effective and sustainable supplementation strategies at farm level and knowledge transfer activities to communicate best practice as regards MV supplementation in pasture-based systems of prime lamb production. The objective of this study was to establish the MV supplementation practices on Irish sheep farms and the knowledge and opinions of farmers in relation to supplementation strategies and deficiencies.

MATERIALS AND METHODS

A supplementary survey was undertaken in addition to the core Teagasc NFS in 2016 to collect information on the knowledge and opinions of farmers with respect to MV supplementation strategies and deficiencies and their use of MV supplements.

Survey Design

A survey was developed, that contained 22 questions, to ascertain an understanding of on-farm practices, and farmer's knowledge and opinions in relation to MV supplementation on sheep farms. The questions within the survey were predominantly closed; however, some open ended questions were included. The questions were phrased to avoid leading the respondent to a given choice. A workshop was undertaken with the Teagasc NFS farm recorders who conducted the survey. All of the questions within the survey were discussed with attention to the clarity of the questions asked and any possible farmer respondent issues. The initial draft survey was then piloted by a number of the NFS farm recorders (n = 10) to assess the likely farmer response burden and to identify any questions that were seen as problematic in terms of interpretation by farmer respondents. The finalized survey deployed as part of the Teagasc NFS was amended based on feedback from the pilot survey.

The survey contained questions on:

i) current MV supplementation practices; respondents were asked if they offered concentrates to their sheep as a source of MV alone and if they offered MV supplementation in addition to concentrate feed. Details were provided of MV supplementation for all sheep groups including MV supplemented, method of supplementation and the perceived responses to supplementation. Respondents were also asked to rank the factors in order of importance that influence their choice of supplementation method;
ii) why the farmer respondents undertook their decision in relation to MV supplementation;
iii) the farmer's opinions regarding the importance of 6 trace minerals for sheep production [Cobalt (Co), Copper (Cu), Iodine (I), Zinc (Zn), Selenium (Se) and Manganese (Mn)] and what deficiency signs/symptoms they were aware of for each of these minerals;
iv) their knowledge of the (clinical) signs of mineral deficiency in sheep and what they consider to be the main health/production problems associated with MV deficiencies;
v) how they describe their level of education/knowledge on the MV requirements of sheep.

Farm Selection and Survey Method

The MV supplementation questionnaire was administered to all farmers with a sheep enterprise that participated in the Teagasc NFS. The Teagasc NFS sample is a stratified random sample of farms selected each year in conjunction with Ireland's Central Statistics Office (CSO), designed to be statistically representative of farms (differing in economic size and type of farming) in Ireland with in excess of €8,000 euro Standard Output (Dillon et al., 2018). Each farm in the survey is assigned a weighting factor (based on the most recent Census of Agriculture) provided by the CSO, so that the results of the survey are representative of the national population of farms. Using the EU farm typology as set out in Commission Decision 78/463, and its subsequent amendments, all farms within the NFS are assigned to six farm systems (dairying, cattle rearing, cattle other, sheep, tillage, and mixed livestock) on the basis of farm gross output, as calculated on a standard output basis. On an annual basis, Teagasc NFS supplementary surveys on specific topics are undertaken in addition to the core Teagasc NFS, which collects microeconomic data on Irish farming. The MV supplementation survey, together with the core Teagasc NFS survey, were completed on paper, on farm, by respondents in conjunction with a trained farm recorder from the Teagasc NFS team.

Data Management and Statistical Analysis

The survey data were inputted (by NFS recorders) on a separate MS Excel (Microsoft Corporation, Redmond, USA) spreadsheet for each respondent. Unanswered questions were recorded as "nonresponses" and the survey data collected were screened for anomalies. Any anomalies identified were checked and resolved, or excluded from the sample. Of the 184 survey responses, 177 survey responses (96%) were deemed to be usable. Seven survey responses were excluded from further analysis because farm physical and financial performance data were not available from the core NFS survey. The percentages reported in this paper are of those who responded to the question being reported (unless otherwise indicated) and are weighted as described earlier. Descriptive statistics were used to summarize survey results. Differences between group means, for adopters (characteristics of farms where MV is practiced) and nonadopters (characteristics of farms where MV is not practiced) were analyzed using a Student's t-test (for continuous variables) and Pearson chi-square tests (for categorical variables) in Stata 13 (StataCorp, Texas, 2013). Formal agricultural training is defined as the farmer having completed a farm apprenticeship or any full-time or part-time courses on farming (CSO, 2012).

RESULTS

Farm Profile

Eighty-five percent of surveyed farmers had access to an agricultural advisor or consultant. Farm size, ewe flock size, and productivity data of the farms surveyed are presented in Table 1. The mean stocking rate and number of lambs reared per ewe joined were 7.0 ewes/ha and 1.32 lambs/ewe, respectively. Details of Teagasc NFS farm enterprise classification and the sheep production system of the respondents are presented in Table 2. Fifty-four percent of the farms were classified as mainly sheep farms and 30% were classified as mainly cattle (rearing and other) farms. The mean concentrate input

Table 1. Range in farm and flock performance (n = 177)

Descriptor	Mean	Minimum	Maximum
Farm size, ha	66.5	7.7	1,117
Sheep forage area[1], ha	21.7	1.4	351
Average number of ewes	123	64	1,298
Stocking rate, ewes/ha	7.0	0.2	19.5
Lambs reared/ewe joined	1.32	0.23	2.15
Farmer age, years	55.5	17	84
Flock size, no of ewes	% of respondents		
≤50	27		
51–100	28		
100–200	28		
>200	16		

[1]The total adjusted area under grass (including rough grazing) plus adjusted commonage area (share of unenclosed lands) for sheep enterprise.

Table 2. Details of farm classification and sheep system (n = 177)

Teagasc NFS Farm classification[1]	% of farms
Mainly Sheep	54
Cattle other	25
Dairying	7
Cattle rearing	5
Tillage	5
Other	4
Sheep system	
Lowland lamb[2]	80
Lowland lamb/fattening[3]	2
Hill	17
Other	1

[1]Farm classification refers to the dominant system on the farm based on the proportion of total standard output which comes from each enterprise.
[2]Lowland flocks: main enterprise is breeding ewes and lambs are slaughtered or sold as stores.
[3]Lowland flocks: breeding ewe flock and lambs are slaughtered or sold as stores. Also sizeable purchasing of store lambs which are slaughtered or sold for breeding.

was 100 kg/ewe/year and there was no significant difference ($P > 0.05$) in concentrate input between adopter farms (MV supplementation is practiced) and nonadopter farms (MV supplementation is not practiced).

Supplementation

Seventeen percent of farmers offered concentrates to their sheep as the only source of MV supplementation, 32% supplemented their flock with supplemental MV only (by a method other than concentrates, e.g. oral drench). Thirty-eight percent of all farmers offered both concentrates and additional MV supplementation to their flock, whereas 13% offered no supplementary MV (either in concentrates or by any other method). The main reasons among the 65% of respondents who provided an explanation for not supplementing with MV are presented in Table 3. The absence of perceived MV deficiency problems was identified as the main reason for not supplementing.

Twenty-three percent of the respondents who do not currently supplement their flock with MV (in addition to concentrate feed) had previously supplemented with MV. The reasons for discontinuing MV supplementation were that there was no perceived requirement for MV supplementation on the farm (80%), no perceived response by sheep to previous supplementation practices (12%) and the cost of mineral supplements (8%). Of those respondents who do not currently supplement with MV in addition to concentrates, 22% would consider supplementing in the future primarily if there was a perceived requirement for MV supplementation (42%) or if flock health problems became an issue (38%).

Table 3. Main reasons for not supplementing with minerals and vitamins in addition to concentrate feed (n = 34)

Reason	% of respondents[1]
No deficiency problems identified	84
Small flock size	9
Lack of information on requirements, when to supplement etc.	3
Cost	2
Concentrate provides adequate MV[2]	2
Labour	0

[1]Weighted percentage – weighting factors (based on the most recent Census of Agriculture) provided by the Central Statistics Office.
[2]Mineral and vitamin.

Supplementation Decisions

Twenty-two percent of farmers who supplement with MV in addition to concentrate feed administer supplements based on results from laboratory analysis (soil, herbage, blood, and/or tissue analysis). Results of blood (10%) and soil (9%) were the main laboratory analysis on which decisions to supplement were based. Thirteen percent supplement based on advice from their veterinary surgeon. Of the respondents who identified veterinary advice as the basis for supplementation practices, 30% indicated that this advice was based on laboratory analysis results.

Farmers who supplemented based on results from laboratory analysis were asked who advised them to undertake the analysis. Seventy-nine percent who supplemented based on soil analysis results undertook the soil analysis on the advice of their agricultural advisor/consultant. Sixteen percent undertook soil analysis on their own initiative, whereas 5% undertook soil analysis based on advice received from their veterinarian. All farmers who undertook blood analysis did so on the advice of their veterinarian.

The majority (65%) of decisions to supplement with MV were taken for reasons other than laboratory analysis or veterinary advice, with only 32% specifying the "other" reason. Of those specifying the "other" reason, 51% said their decision to supplement was tradition and/or previous experience, while 23% said their decision was on advice received from their local retail outlet (merchant, co-op, supply store) counter/sales assistant. The advice of an agricultural advisor/consultant was cited by 17% of respondents while 9% supplemented because a neighboring farmer supplements.

Health/Production Problems

Respondents were asked what they consider to be the top three health/production problems associated with MV deficiencies.

Nineteen percent of respondents either did not know or chose not to list any health or production issues. Forty-nine percent of respondents (excluding don't know and nonresponses) associated poor thrive (ill thrift) or poor body weight gain as the main problem associated with MV deficiency. Thirty-eight and 67% did not list a second and third most common health/production problem, respectively. Twenty-three and 16% (excluding don't know and nonresponses) considered reduced fertility and higher incidences of lameness as the second and third most common health/production problem associated with MV deficiency, respectively.

Only 6% of all respondents had flock health or performance issues associated with MV deficiency diagnosed by a veterinarian. Forty-six percent of the diagnoses were established more than 20 years ago, 24% were established between 10 and 20 years ago, while only 30% were established in the last 5 years. The problems identified on farm by veterinarians are presented in Table 4. Cu (including swayback) was identified as the main MV deficiency.

Supplementation Practices

The MV supplementation practices for ewes and for lambs pre and post weaning are presented in Tables 5 and 6, respectively. Pregnancy (78%), lactation (61%), and pre-mating (48%) were the most common stages that farmers supplemented ewes with MV. Generic MV products (containing multiple minerals and vitamins) were most commonly supplemented followed by Co only products. On average, mineral buckets (free access solidified molasses-based licks containing MV and in plastic containers) were the most common method of supplementation to ewes, drenching (oral dosing with MV containing liquid) was the most common method of supplementing lambs.

Thirty-six percent of farmers who supplemented, supplemented their rams. Generic MV (56%) and Co plus vitamin B_{12} (13%) were the most used products. Drenching (44%) was the most popular method of supplementing rams, followed by mineral buckets (30%), with boluses/bullets administered by just 10% of farmers. When asked why they provided MV supplementation to rams, 40% of farmers responded to increase litter size while 15% expected to increase fertility and thrive and have stronger rams.

Survey respondents were asked to rank, in order of importance, the factors that influence their choice of MV supplementation method. Ease of use and labor requirements were ranked as the most important factors influencing their choice of MV supplementation method. Cost was the second most important factor followed by the expected efficacy of the method of supplementation.

Knowledge/Opinion on Trace Minerals

Respondents were asked to rank six trace minerals (Co, Cu, I, Zn, Se, and Mn) in order of "how important they feel they are in sheep production on their farm". Co, Se and I were ranked as the first, second, and third most important trace minerals, respectively. Respondents considered Mn, Cu, and Zn to be the fourth, fifth, and sixth most important trace minerals respectively, for sheep production. Forty-six percent of farmers claimed to have limited or no education/knowledge on mineral requirements of sheep production. Of all survey respondents only 22% described their level of education/knowledge on sheep mineral requirements as good or excellent, while 32% claimed to have reasonably good education/knowledge.

Association with Productivity and Profitability

A comparison of the characteristics of adopters and nonadopters of MV supplementation among lowland lamb

Table 4. Flock health problems or performance issues diagnosed by a veterinarian associated with mineral/vitamin deficiency on respondent's farms (*n* = 11)

Problem	% of respondents[1]
Cu deficiency (including swayback) only	48
Cu and Se deficiency only	34
Co and Se deficiency only	8
I deficiency only	6
I, Co and Se deficiency only	4

[1]Weighted percentage – weighting factors (based on the most recent Census of Agriculture) provided by the Central Statistics Office.

Table 5. Mineral and vitamin supplementation practices for ewes (*n* = 125 flocks)

	% farmers who supplement[1]	Most supplemented MV[1,2], %	2nd most supplemented MV[1,2], %	Most used method[1],%	2nd most used method[1], %	1st expected response[1], %	2nd expected response[1], %
Pregnant	78	Generic MV mix[3] (74)	Co only (12)	Mineral buckets[4] (64)	Drench (15)	Increased litter size (34)	Reduced barrenness (19)
Lactating	61	Generic MV mix (70)	Co only (14)	Mineral buckets (67)	Drench (14)	Reduced barrenness (33)	Increased litter size (20)
Post weaning	22	Generic MV mix (65)	Co only (19)	Mineral buckets (61)	Drench (23)	Increased litter size (19)	Increased BW gain (17)
Pre mating	48	Generic MV mix (52)	Co plus Vitamin B_{12} (13)	Drench[5] (55)	Mineral buckets (22)	Increased litter size (40)	Reduced barrenness (15)
Hoggets/ewe replacements	37	Generic MV mix (40)	Co only (28)	Drench (52)	Mineral buckets (23)	Increased BW gain (17)	Improved health (17)

[1]Weighted percentage – weighting factors (based on the most recent Census of Agriculture) provided by the Central Statistics Office.
[2]Mineral and Vitamin.
[3]Products containing multiple minerals and vitamins.
[4]Free access solidified molasses-based licks containing MV and in plastic containers.
[5]Oral dosing with MV containing liquid.

producers is presented in Table 7. There was no significant difference ($P > 0.05$) in the number of lambs reared/ewe joined, gross output/ewe or gross margin/ewe between adopters and nonadopters. MV supplementation is more likely to be practiced on farms where sheep production is the main enterprise ($P < 0.01$). Farmers who have received formal agricultural training are more likely to supplement their flock ($P < 0.01$). Farmer age, soil classification (good or bad), access to an agricultural advisor or farming fulltime or part-time did not affect ($P > 0.05$) the likelihood of supplementing with minerals.

A comparison of the characteristics of adopters and nonadopters of mineral supplementation of ewes pre-mating by lowland lamb producers is presented in Table 8. Farmers who supplemented ewes pre-mating with MV had higher stocking rates (ewes/ha) ($P < 0.01$) compared to those who did not supplement ewes pre-mating. However, supplementation with MV pre-mating did not increase ($P > 0.05$) the number of lambs reared per ewe joined or gross margin per ewe. The supplementation of ewes pre mating with MV is more likely to be practiced ($P < 0.01$) where sheep production is the main enterprise on the farm.

DISCUSSION

To the best of our knowledge, this is the first study of the determinants of MV supplementation strategies of sheep farmers in pasture-based sheep producing systems, and their knowledge and opinions in relation to these strategies and MV deficiencies.

The mean flock size reported in the current study (123 ewes) is similar to that reported (133 ewes) by the Teagasc National Farm Survey in 2016 (Dillon et al., 2017) but greater than the mean flock size reported in the National Sheep and Goat Census (Department of Agriculture, Food and the Marine, 2019), and the Farm Structures Survey (CSO, 2018). The larger mean flock size reflects the exclusion of small farms (those with a standard output of less than €8,000) from the sampling frame of the Teagasc NFS (Dillon et al., 2017). The average stocking rate (ewes/ha) and number of lambs reared per ewe joined in the current study were similar to those reported for Irish sheep farms in the 2016 Teagasc NFS (Dillon et al., 2017).

Mineral deficiency results in poor animal performance and decreased farm profitability. The concentrations of Co, Cu, I, Zn, Se, and Mn in Irish pastures range from 0.03 to 0.2, 2

Table 6. Mineral and vitamin supplementation practices of lambs (n = 125 flocks)

	% farmers who supplement[1]	Most supplemented MV[1,2], %	2nd most supplemented MV[1,2], %	Most used method[1], %	2nd most used method[1], %	1st expected response[1], %	2nd expected response[1],%
Pre weaning	27	Generic MV mix[3] (39)	Co only (34)	Drench[4] (68)	Mineral buckets[5] (27)	Increased BW gain (51)	Higher carcass weight (33)
Post weaning	51	Co only (39)	Generic MV mix (28)	Drench (74)	Mineral buckets (13)	Increased BW gain (61)	Higher carcass weight (16)

[1]Weighted percentage – weighting factors (based on the most recent Census of Agriculture) provided by the Central Statistics Office.
[2]Mineral and Vitamin.
[3]Products containing multiple minerals and vitamins.
[4]Oral dosing with MV containing liquid.
[5]Free access solidified molasses-based licks containing minerals and in plastic containers.

Table 7. Characteristics of adopters and non-adopters of mineral and vitamin supplementation in lowland lamb production flocks (n = 140)

Variable	Adopters (n = 101 flocks)[1]		Nonadopters (n = 39 flocks)[1]		P-value
	Mean	SD	Mean	SD	
Gross output/ewe, €	142.8	53.62	131.8	40.27	NS
Gross margin/ewe, €	77.0	50.68	65.6	42.63	NS
Lambs reared/ewe joined	1.39	0.26	1.34	0.26	NS
Ewes/ha	7.10	2.76	7.00	2.58	NS
Number of ewes	115.3[a]	132.59	71.6[b]	100.22	<0.05
Concentrates per ewe, kg	95.2	62.37	110.2	70.98	NS
Concentrate as MV[2] supplementation, %	0.54	0.50	0.53	0.51	NS
Farm size, ha	47.4	30.78	38.3	31.26	NS
Formal agricultural training[3], %	0.54[a]	0.50	0.18[b]	0.39	<0.001
Access to agricultural advisor, %	0.71	0.46	0.69	0.47	NS
Age, years	56.3	11.36	53.8	11.19	NS
Veterinary costs/ewe, €	14.02	7.36	11.43	6.76	NS

[a,b] Within a row, means denoted by a different letter indicate significant differences ($P \leq 0.05$). NS, not significant ($P > 0.05$).
[1]Weighted data — weighting factors (based on the most recent Census of Agriculture) provided by the Central Statistics Office.
[2]Mineral and vitamin.
[3]Where the farmer has completed a farm apprenticeship or any full-time or part-time courses on farming.

Table 8. Characteristics of adopters and non-adopters of mineral and vitamin supplementation of ewes pre-joining in lowland lamb production flocks (n = 140)

Variable	Adopters (n = 50 flocks)[1]		Nonadopters (n = 90 flocks)[1]		P-value
	Mean	SD	Mean	SD	
Gross output/ewe, €	149.4	54.38	134.5	47.19	NS
Gross margin/ewe, €	77.4	46.93	71.6	49.29	NS
Lambs reared/ewe joined	1.41	0.27	1.36	0.26	NS
Ewes/ha	8.0^{a}	2.86	6.7^{b}	2.52	<0.01
Number of ewes	143.5^{a}	175.02	81.4^{b}	84.82	<0.001
Concentrates per ewe, kg	105.3	66.68	97.3	64.74	NS
Concentrate as MV[2] supplementation, %	0.56	0.50	0.52	0.50	NS
Farm Size, ha	50.36	33.67	41.73	29.53	NS
Formal agricultural training[3], %	0.65^{a}	0.48	0.32^{b}	0.47	<0.001
Access to agricultural advisor, %	0.75	0.44	0.68	0.47	NS
Age, years	55.4	12.51	55.6	10.77	NS
Veterinary costs/ewe, €	14.83	5.93	12.43	7.72	NS

[a,b]Within a row, means denoted by a different letter indicate significant differences ($P \leq 0.05$).
NS, not significant ($P > 0.05$).
[1]Weighted data — weighting factors (based on the most recent Census of Agriculture) provided by the Central Statistics Office.
[2]Mineral and vitamin.
[3]Where the farmer has completed a farm apprenticeship or any full-time or part-time courses on farming.

to 15, 0.07 to 0.30, 20 to 60, 0.03 to 0.5 and 20 to 300 mg/kg DM, respectively (Parle et al., 1998). The concentrations of many minerals in grazed herbage vary during the grazing season (Curran et al., 2014; Kavanagh et al., 2014; Keady et al., 2022). Thus, many pastures grazed by sheep are deficient in one or more minerals at different times throughout the grazing season. Mineral deficiencies have also been reported in pasture-based sheep producing regions in Australia (Lee et al., 1999) and New Zealand (Knowles and Grace, 2014). Consequently, mineral supplementation may be required to improve animal performance.

However, mineral supplementation should not be the first intervention or management practice change of farmers attempting to remedy poor animal performance and should only be undertaken where there is an identified physiological requirement (Kendall, 2014; Kendall et al., 2019). MV supplementation activities are associated with both financial and labor costs. The causes of suboptimal animal performance are often inadequate grassland management practices (thus impacting on nutrient intake) and parasite control strategies (Keady et al., 2017) and not mineral deficiency *per se*, and MV supplementation in such instances is unlikely to improve farm profitability. Examining other factors which affect ewe and lamb performance on pasture, such as grazing management, herbage feed value, parasite control etc. should be the first step in addressing poor animal performance (Keady and Hanrahan, 2006; Kendall et al., 2019) before mineral deficiency is suspected and MV supplementation undertaken.

Supplementation strategies for MV used by farmers need to be targeted as there is evidence of over supplementing ruminants (Kendall et al., 2015; Sinclair and Atkins, 2015). The need for more targeted use of MV supplements is evident as only 6% of respondents have had actual flock health problems or performance issues diagnosed, which were associated with MV deficiencies. Results from the present survey shows that most farmers using MV supplements do so in the absence of consultation with a veterinarian, or agricultural advisor/consultant. The finding that veterinarians are not very involved in farmers' decision making in relation to MV supplementation is not surprising. ADAS (2007) reported, based on a survey of 2,500 UK sheep producers, that 68% of sheep farmers only use veterinarians for emergency treatments of sick sheep. ADAS (2007) also reported that only 22% of UK sheep farmers had regular contact with their veterinarian.

Availability of laboratories which perform mineral analyses and the possible lack of farmer knowledge on how to access laboratory services, cost of the analysis and issues relating to appropriate sample type and timing of sampling may be potential factors limiting the use of laboratory analysis as a basis for supplementation. Lapple et al. (2015) reported that sheep farmers were less likely to adopt innovative agricultural technologies such as laboratory analysis. Moreover, farmer age and engagement in off-farm employment also had a negative effect on the adoption of innovative technologies (Lapple et al., 2015). The average age of respondents in the current study was 55.5 years. Thirty-two percent of Irish sheep farmers are engaged in off-farm employment (Dillon et al., 2017). Availability of mineral supplementation products and marketing strategies of companies which have focused on including many MV in their supplement products (Kendall et al., 2019), may also explain the widespread use of such products without an identified need for supplementation.

The low importance of obtaining evidence-based advice regarding MV supplementation highlights the need for more communication between farmers and their advisors/consultants and veterinarians. Farmers do not rate their level of education/knowledge on sheep mineral requirements highly. The apparent lack of knowledge of farmers relating to mineral nutrition is evident from their expectations in relation to likely animal responses to supplementation and also the methods of supplementation used. For example, the main production responses expected (increased litter size and reduced barrenness) from supplementing ewes during pregnancy and lactation are not established benefits from MV supplementation at that stage in the production cycle. The expected responses of increased litter size and reduced barrenness are more likely to be achieved by having ewes in appropriate body condition at joining (Hanrahan, 1990) and through targeted MV supplementation during the pre-mating period (Munoz et al., 2009), when only 48% of the survey respondents indicated they supplemented their ewes.

The prevalence of mineral buckets as the preferred method of supplementation in late pregnancy needs to be questioned, considering the intake variability associated with this method of supplementation (Crosby et al., 2004). The popularity of the use of mineral buckets is probably due to their ease of use rather than expected efficacy of the supplementation method and also as they provide additional energy to ewes. The widespread use of mineral buckets provides evidence that farmers lack knowledge of the efficacy and advantages and disadvantages of the various supplementation methods. Mineral boluses (bullets) are not a widely used method of supplementation, even though they may have long-term efficacy and thus the capacity to reduce labor costs (Grace and Knowles, 2012). Boluses are more expensive than other methods of supplementation (Grace and Knowles, 2012). Also there are some concerns regarding the possible regurgitation of boluses (McDowell, 2003) and the duration of efficacy of some boluses which may explain the limited use of the method. Other methods of mineral supplementation, e.g. drenching, have short-term efficacy for some minerals, e.g. cobalt (Williams et al., 2017), and are not the ideal method of supplementing grazing livestock, because the requirement for repeated administrations is associated with high labor requirements (Grace and Knowles, 2012). Knowledge transfer by advisors/consultants and veterinarians should focus on educating sheep producers on the likely animal responses to MV supplementation and the efficacy of various methods of supplementation.

Supplementation with MV represents the financial cost of purchase and labor expense to administer, therefore supplementation needs to deliver an increase in output value and profitability to be economically justified. A comparison of gross margin per ewe between adopter and nonadopter farms showed no economic benefit to supplementation even prior to including labor costs associated with MV administration. The number of lambs reared per ewe joined, one of the key determinants of profitability in pasture-based prime lamb production sheep systems (Keady and Hanrahan, 2006), was not improved due to supplementation pre-joining.

The potential for self-selection bias due to initial differences between adopter and nonadopter farms both in terms of their observed and unobserved characteristics was considered as self-selection may emerge in these two forms (Cerulli, 2015). In addition, both positive and negative self-selection was considered although not modeling either explicitly (Cai and Pandey, 2015). The possibility that, in the absence of MV supplementation, the average output and profitability would have been lower for adopters relative to nonadopters was considered. This counterfactual scenario is plausible in circumstances where adopters have a greater requirement for additional MV supplementation relative to nonadopters. Such a scenario would involve negative self-selection bias, a form of bias which is sometimes overlooked but is often considered in relation to specific topics such as within labor migration literature (see McKenzie and Rapoport, 2010).

An observed variable representing a formal estimate of MV deficiency on the study farms is not available, which could be a source of negative self-selection bias. However, the influence of observed variables related to concentrate use, which may have acted as a partial substitute for MV supplementation whilst addressing MV deficiencies was considered. There was no significant relationship between the level of concentrate use per ewe and the adoption decision thereby indicating no evidence of widespread substitution between concentrates and MV supplementation. In addition, there was no significant relationship between adoption and the self-reported use of concentrates as a source of MV supplementation. The possible influence of unobserved characteristics such as farm management ability in influencing both the adoption decision and profitability was also considered. The absence of a significant difference between the two groups in terms of output and profitability means that we did not further explore the potential role of unobserved positive self-selection.

In conclusion, supplementation with MV is widely practiced on Irish sheep farms. Most supplementation decisions are undertaken in the absence of veterinary advice or laboratory results and are therefore not evidence based. Supplementation with MV did not alter the profitability of farms. Supplementation needs to be more targeted and only take place where there is an identified requirement, based on the results of laboratory analysis. Farmers lack knowledge and information in relation to the likely responses from mineral supplementation and the effects of MV deficiencies on sheep performance. Knowledge transfer activities need to be designed to communicate best practice as regards MV supplementation, in particular when is supplementation required, the most appropriate strategy and expected responses in sheep production systems.

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Conflict of Interest Statement

None declared.

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