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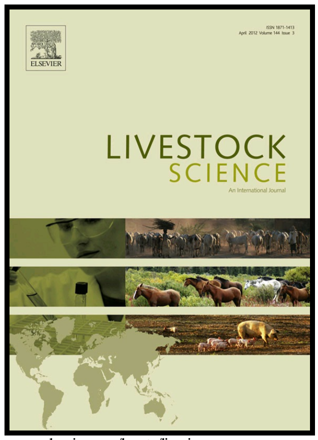

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Investigating the role of stocking rate and prolificacy potential on profitability of grass based sheep production systems

A. Bohan [1, 2], L. Shalloo[1], P. Creighton[3], E. Earle[2, 3], T. M. Boland[2] and N. McHugh[1]

[1]*Animal & Grassland Research and Innovation Centre, Teagasc, Moorepark, Fermoy, Co. Cork, Ireland.*

[2]*School of Agriculture & Food Science, University College Dublin, Ireland.*

[3]*Animal & Grassland Research and Innovation Centre, Teagasc, Athenry, Co. Galway, Ireland.*

Corresponding author: Alan Bohan; alan.bohan@teagasc.ie

Abstract

The objective of this study was to simulate and compare the profitability of a grass based sheep production system under three stocking rates and two prolificacy rates. Analysis was conducted using the Teagasc Lamb Production Model (TLPM), a stochastic budgetary simulation model of a sheep farm. Experimental data from the Teagasc Athenry Research Demonstration Flock was used to parameterise the model at three stocking rates (10, 12 and 14 ewes/ha) and two prolificacy potentials (1.5 and 1.8 lambs weaned per ewe joined to the ram). The TLPM assessed the performance of the key factors affecting profitability and was also used to evaluate the spread in profitability associated with some stochastic variables included in the analysis. The number of lambs weaned per hectare increased with stocking rate and prolificacy potential from 16 lambs/ha to 27 lambs/ha resulting in carcass weight produced per hectare ranging from 272 kg/ha to 474 kg/ha. Increasing stocking rates resulted in lower individual lamb performance from grass and milk, thereby increasing the proportion of lambs which required concentrate for finishing, which resulted in higher input costs on a per animal basis. As the number of lambs weaned per hectare increased, net profit increased from €361/ha to €802/ha. Across all stocking rates, increasing weaning rate from 1.5 to 1.8 lambs weaned per ewe joined increased net profit, on average, by €336/ha. Increasing stocking rate, at 1.5 lambs weaned per ewe joined, increased net profit on average by €15/ha while increasing stocking rate, at 1.8 lambs weaned per ewe joined increased net profit on average by €87/ha. Risk analysis showed that across all stocking rates the high prolificacy scenarios achieved greater profits across the variation in input variables. Results from this study indicate that lambs weaned per hectare linked with grass growth and utilisations are the key drivers of profitability on Irish grass based sheep production systems.

Keywords: Bio-economic model, stocking rate, prolificacy, farm profit

1 Introduction

Stocking rate and ewe prolificacy have been described as key drivers of flock productivity and output across both Irish and international sheep systems (Keady and Hanrahan, 2006; Ho et al., 2014), and therefore are key determinants of farm profitability in grass based sheep production systems. Prolificacy, although not as pertinent in beef or dairy systems, has been shown to be of paramount importance in the profitability potential of sheep flocks, with higher numbers of lambs weaned per hectare resulting in higher profit margins (Teagasc, 2016a). Stocking rate has long been described as a key factor in the productivity and profitability of pasture based dairy farms (Macdonald et al., 2008; McCarthy et al., 2011). Previous studies have shown that increased stocking rate increases total pasture production, quality and utilisation, as well as, increasing output per unit area across beef, sheep and dairy enterprises, however, individual animal performance generally reduces (Conway, 1963; Drennan, 1971; McCarthy et al., 2011). Current national figures for Irish sheep flocks show that the average lowland stocking rate and prolificacy potentials are 7.4 ewes/ha and 1.3 lambs weaned per ewe joined to the ram, respectively (Teagasc, 2016b). In comparison to international estimates for the UK (18.3 lambs weaned per hectare) and New Zealand (12.7 lambs weaned per hectare) (Connolly, 1999), Ireland's average number of lambs weaned per hectare (9.6) remains low, indicating that there is potential scope for improvements in this key performance indicator. Previous studies have assessed the effect of stocking rate and ewe prolificacy on ewe and lamb performance, lamb output (Earle et al., 2016) and on total flock performance (Earle et al., 2017) in grass based sheep production systems, but the economic performance of such systems have not been quantified to date.

The objective of this paper therefore was to assess the profitability of Irish grass based sheep production across three stocking rates and two prolificacy potentials using experimental data as outlined by (Earle et al., 2016; Earle et al., 2017). Risk analysis was also conducted to assess the profitability of alternating stocking rate and prolificacy potential by varying levels of key input parameters.

2 Materials and methods

2.1 Bio-economic model

The Teagasc Lamb Production Model (TLPM) is a bio-economic computer simulation model that simulates a sheep production system using specific inputs to derive physical and financial outputs (Bohan et al., 2016). The model can be used to assess the effects of institutional, technical or environmental changes on the systems physical and financial outputs. The model integrates animal inventory and valuation, lamb drafting, feed requirements, land and labour utilisation and economic analysis. The TLPM simulates a 12 month cycle of a farm with the production year beginning at mating and is driven by the net energy requirement of the flock for maintenance, growth, body condition change, pregnancy and lactation (O'Mara, 1996). To meet the net energy requirement of the flock the TLPM calculates the flock energy requirement and creates a feed budget of grass, grass silage and concentrate depending on time of year and stage of production. Key model outputs include: farm cash flow, profit and loss and balance sheet, feed supply and demand, livestock trading schedule and physical ratios. The stochastic nature of the TLPM allows risk analysis to be conducted on varying modelled scenarios.

2.2 Stocking rate and prolificacy potential scenarios

Six stocking rate and prolificacy potential scenarios were investigated in the current study (Table 1) using data obtained from the Sheep Research Demonstration Flock, Teagasc, Animal and Grassland Research Centre, Mellows Campus, Athenry, Co Galway, Ireland (54° 80'; N; 7°25' W), from the production years 2013 to 2015, inclusive (Earle et al., 2016, Earle et al., 2017). The experimental design and flock management are described in detail elsewhere (Earle et al., 2017), but in summary the study was a 2 x 3 factorial design, consisting of two differing ewe prolificacy potentials (medium prolificacy - 1.5 lambs weaned per ewe joined and high prolificacy - 1.8 lambs weaned per ewe joined), which were assigned to one of three stocking rates 10, 12 or 14 ewes/ha. Detailed information on key performance indicators such as mortality, lamb growth rates and grass utilisation were available on each of the six scenarios investigated (Table 2; Earle et al., 2016, Earle et al., 2017). All scenarios were simulated on a 20 ha farm and the key input variables for each scenario are outlined below and are summarised in Table 1. Grass growth and utilisation was increased in line with flock energy requirements when stocking rate and ewe prolificacy increased, as outlined below and in Table 2.

2.2.1 Scenario 1: Low Stocking Rate - Low Prolificacy

The first scenario (scenario 1) had an average stocking rate of 10 ewes/ha across the year, which required 213 ewes to be joined to the ram at mating. The low prolificacy potential ewes (1.5 lambs weaned per ewe joined) were dictated by sire breed and were Suffolk crossbred ewes and had average live weight of 80.8 kg at mating. The pregnancy scan rate achieved in this scenario was 1.7 lambs per ewe joined to the ram, which after accounting for lamb mortality equated to 1.5 lambs weaned per ewe joined. Total lamb mortality (pregnancy scanning to sale) was 12.6%. The average lamb birth weight was 5.2 kg; average lamb weaning weight for the scenario was 31.5 kg. Lamb drafting commenced in June and ceased in January, with 75% of the lambs slaughtered by October 1st off a grass only diet. Ewe replacement rate was 18.2%, which consisted of 6.4% mortality and 11.8% culling; this resulted in the retention of 38 ewe lambs for replacement. The average annual grass growth was 10,071 kg dry matter (DM)/ha and 8,063 kg DM/ha (80%) was utilised.

2.2.2 Scenario 2: Medium Stocking Rate - Low Prolificacy

The stocking rate in scenario 2 was on average 12 ewes/ha across the production year, which equated to the mating of 256 ewes. The low prolificacy potential (1.5 lambs weaned per ewe joined to the ram) was represented by Suffolk crossbred ewes, with an average live weight of 77.9 kg at mating. The pregnancy scan rate achieved in scenario 2 was 1.7 lambs per ewe joined to the ram, which after lamb mortality equated to 1.5 lambs weaned per ewe joined. Total lamb mortality (pregnancy scanning to sale) was 13.4%. The average lamb birth weight was 5.1 kg; average lamb weaning weight for scenario 2 was 32.6 kg. Lamb drafting commenced in June and ended in January, with 55% of the lambs slaughtered by October 1st off a grass only diet. Ewe replacement rate was 19.3% which resulted in the retention of 49 ewe lambs for replacement purposes. The 19.3% replacement rate consisted of 5.9% mortality and 13.4% culling. Grass growth for scenario 2 was 11,606 kg DM/ha and grass utilisation was 9,872 kg DM/ha (85%).

2.2.3 Scenario 3: High Stocking Rate - Low Prolificacy

Scenario 3 had an average stocking rate across the production year of 14 ewes/ha which resulted in the mating of 294 ewes. The low prolificacy potential (1.5 lambs weaned per ewe joined to the ram) Suffolk crossbred ewes had an average live weight of 79.7 kg at mating. The pregnancy scan rate for scenario 3 was 1.8 lambs per ewe joined to the ram, which after accounting for lamb mortality equated to 1.5 lambs weaned per ewe joined. Total lamb mortality (pregnancy scanning to sale) was 17.8%. The average lamb birth weight was 5.0 kg, with an average lamb weaning weight of 31.3 kg. Lamb drafting commenced in June and ended in January with 47% of the lambs slaughtered by October 1st off a grass only diet. Ewe replacement rate was 13.1% (4.9% mortality and 8.2% culling) resulted in 38 ewe lambs being retained as replacements. Grass growth for scenario 3 was 12,785 kg DM/ha and the corresponding utilisation value was 11,511 kg DM/ha (90%).

2.2.4 Scenario 4: Low Stocking Rate - High Prolificacy

Scenario 4 had an average stocking rate of 10 ewes which equated to 215 ewes being joined to the ram at mating. The high prolificacy potential (1.8 lambs weaned per ewe joined to the ram) was achieved based on Belclare sired ewes with an average live weight of 79.3 kg at mating. The pregnancy scan rate for scenario 4 was 2.2 lambs per ewe joined to the ram, which after lamb mortality equated to 1.8 lambs weaned per ewe joined. Total lamb mortality (pregnancy scanning to sale) was 17.7%. The average lamb birth weight was 4.6 kg; the average lamb weaning weight was 31.6 kg. Lamb drafting commenced in June and ended in December, with 63% of the lambs slaughtered by October 1st off a grass only diet. Ewe replacement rate was 20% (7% mortality and 13% culling), resulting in 42 ewe lambs being retained as replacements. Grass growth for scenario 4 was 11,559 kg DM/ha; grass utilised in scenario 4 was 9,254 kg DM/ha (80%).

2.2.5 Scenario 5: Medium Stocking Rate - High Prolificacy

Scenario 5 had an average stocking rate of 12 ewes/ha across the production year, this equated to 259 ewes joined to the ram at mating. The high prolificacy potential (1.8 lambs weaned per ewe joined to the ram) was achieved through the use of Belclare crossbred ewes, with an average live weight of 77.3 kg at mating. Scenario 4 had a pregnancy scan rate of 2.1 lambs per ewe joined to the ram, which after lamb mortality equated to 1.8 lambs weaned per ewe joined. Total lamb mortality (pregnancy scanning to sale) was 14.6%. The average lamb birth weight was 4.8 kg with an average lamb weaning weight of 28.7 kg. Lamb drafting commenced in June and ended in January, with 68% of the lambs slaughtered by October 1st off a grass only diet. Ewe replacement rate was 22.3%, which consisted of 7.4% mortality and 14.9% culling; this resulted in 56 ewe lambs being retained as replacements. Scenario 5 grew 13,011 kg DM/ha of grass and utilised 11,068kg DM/ha (85%).

2.2.6 Scenario 6: High Stocking Rate - High Prolificacy

The average stocking rate across the production year for scenario 6 was 14 ewes/ha average, this resulted in the mating of 299 ewes. Belclare crossbred ewes represented the high prolificacy potential (1.8 lambs weaned per ewe joined to the ram) and had an average live weight of 73.4 kg at mating. The pregnancy scan rate for scenario 6 was 2.1 lambs per ewe joined to the ram, after accounting for lamb mortality this equated to 1.8 lambs weaned per ewe joined. Total lamb mortality (scan to sale) was 15.7%. The average lamb birth weight was 4.6 kg; the average lamb weaning weight was 30.5 kg. Lamb drafting commenced in June and ended in January, with 50% of the lambs slaughtered off a grass only diet. The ewe replacement rate was 19% (5.9% mortality and 13.1% culling), which equated to 56 ewe lambs being retained as replacements. Grass growth for scenario 6 was 14,374 kg DM/ha, with a corresponding utilisation value of 12,942 kg DM/ha (90%).

2.2.7 Scenario 7: Maintained Grass Growth

In addition to the six scenarios outlined previously a final scenario was modelled to investigate the effect of grass growth on stocking rate and prolificacy potential, whereby grass growth was maintained at the level achieved by the lowest output system (i.e. scenario 1- 10,071 kg DM/ha), while stocking rate and prolificacy were increased in line with scenario 2 to 6. This analysis simulated a scenario where stocking rate and/or prolificacy potential were increased but grass growth remained static, with the additional energy requirements of the flock being supplied through concentrate supplementation. Data from each of the six scenarios were used to simulate six separate March lambing flocks in the TLPM. In all scenarios ewes were mated in early October with pregnancy scanning rate a model input determined based on the three year average from each of the experimental scenarios. The desired weaning rate was calculated from ewe pregnancy scanning rate using lamb mortality data from each of the experimental scenarios. Ewe pregnancy scanning rate determined the energy requirement of the ewe in late pregnancy, with ewes of greater litter sizes requiring more energy and in turn higher concentrate supplementation.

2.3 Model assumptions

Lamb growth rate data was sourced from the Athenry Sheep Research Demonstration Flock (Earle et al., 2016; Earle et al., 2017). Increased litter size affected average lamb growth rate for the first 14 weeks of life as an increase in litter size resulted in lower milk availability per lamb and in turn lower lamb performance (McDonald et al., 2011). Lamb drafting pattern was also sourced from real data (Earle et al., 2016; Earle et al., 2017), using average lamb live weights based on an optimum target carcass weight and kill out percentage. All ewe replacements were sourced from within the flock, with retained ewe lambs lambing for the first time as two year olds, replacement rams were purchased annually. The housing period for ewes and for lambs not drafted prior to the autumn/winter period varied depending on the scenario under investigation due to varying grass supply in early winter. All ewes received concentrates pre lambing depending on pregnancy scanning rate and were returned to grass post lambing. Lambs were drafted for slaughter at a desired live weight using predicted kill out percentage to predict carcass weight. Lambs not drafted by the 1st October received concentrate supplementation until the targeted slaughter weight was achieved.

Total flock energy requirement was calculated within the TLPM using the net energy system, with energy requirement being supplied through grazed grass, grass silage and concentrate; depending on time of year and stage of production. Grass growth, grass utilisation and fertiliser use were all sourced from the Athenry Sheep Research Demonstration Flock (Earle et al., 2016, Earle et al., 2017). The low (10 ewes/ha), medium (12 ewes/ha) and high (14 ewes/ha) scenarios received 113 kg/ha, 145 kg/ha and 181 kg/ha of nitrogen, respectively. Each scenario also received 22 kg/ha of phosphorous and 45 kg/ha of potassium to maintain P and K levels in the soil.

2.4 Economic assumptions

Labour requirement was estimated at eight hours per ewe annually (Connolly, 2000), with one labour unit equivalent to 1,800 hours worked on the farm (Hanrahan et al., 2013). The TLPM assumes that an owner/operator worked a maximum of 300 hours per month, with all additional labour included as hired labour at a cost of €10 per hour. Variable costs (i.e. fertiliser, contractor costs, veterinary, silage, reseeding) and fixed costs (i.e., machinery maintenance and operation, farm maintenance, car, electricity, telephone, insurance) were based on 2016 costs and prices (Bohan et al., 2016).

2.5 Risk analysis

A stochastic simulation was included in the analysis using the @Risk programme (Palisade, 2013) which incorporates Monte Carlo sampling across 10,000 iterations to produce distributions for each stochastic variable investigated. The stochastic variables investigated included: lamb and ewe mortality, grass growth, fertiliser and concentrate costs, lamb and mutton price. For each variable, a minimum, most likely and maximum figure was generated based on industry data recorded between the years 2005 to 2015; the most likely figure was based on the average value for each variable between the years 2013 to 2015 (Table 3). A Program Evaluation and Review Technique (PERT) distribution was fitted to each stochastic variable as a minimum and maximum value for each variable was available from historic data.

3 Results

3.1 Physical

The physical performance of scenario 1 to 6 have been discussed in detail elsewhere (Earle et al., 2016; Earle et al., 2017), however in summary all scenarios were farmed across the same farm area and had a weaning rate of either 1.5 lambs weaned per ewe joined (scenario 1 to 3) or 1.8 lambs per ewe joined (scenario 4 to 6). The difference in stocking rate was caused by increasing the number of ewes joined to the ram at the start of the production year. The number of lambs weaned per hectare increased as stocking rate and ewe prolificacy increased, and ranged from 16 lambs/ha in scenario 1 to 27 lambs/ha in scenario 6 (Table 2). The greater number of lambs weaned per hectare, resulted in a higher carcass weight produced per hectare which rose from 272 kg/ha in scenario 1 to 474 kg/ha in scenario 6 (Table 2). The lower individual lamb growth rates in the higher stocking rate scenarios resulted in more lambs remaining on the farm after October 1st in each year, resulting in greater numbers of lambs receiving concentrate feeding as grass quality and supply decreased (Table 2). This increase in the number of lambs supplemented with concentrates, coupled with the increased concentrate requirement pre lambing of ewes with greater litter sizes resulted in a concentrate consumption of 456 kg/ha in scenario 1 increasing to 888 kg/ha in scenario 6 (Table 2).

3.2 Financial

Lamb sales were the main contributor to total farm income which increased from €1,299/ha to €2,219/ha, with variable costs rising from €774/ha to €1,224/ha in scenario 1 to 6, respectively (Table 4). Fertiliser use, concentrate supplementation and veterinary costs were the main contributors to the variable costs, which were dependent on the number of animals present in each system and the resulting feed demand. The increased hired labour costs were responsible for the majority of the variation in fixed costs between scenarios, which was a function from the number of ewes in each scenario. The average cost of producing a lamb in the low prolificacy scenarios was €75 but decreased to €65 per lamb in the high prolificacy scenarios. This translated into an average net profit of €22/lamb and €31/lamb at the low and high prolificacy scenarios, respectively (Table 5). As stocking rate increased, net profit per lamb decreased, this was due to reduced income per lamb, as lambs were sold later in the year at a lower price per kg, and increased concentrate costs per lamb, as more lambs were present from October onwards for concentrate feeding. As the number of lambs weaned per hectare increased from 16/ha (scenario 1) to 27/ha (scenario 6), net profit increased from €361/ha (scenario 1) to €802/ha (scenario 6). Despite the reduced net profit per lamb, net profit/ha was greater in scenario 6 (Table 4) compared to scenarios 4 and 5 due to the greater number of lambs slaughtered on a per hectare basis (Table 2).

The greatest net profit was achieved in scenario 6, with €2,219/ha in lamb sales, which equated to a gross margin of €1,210/ha and a net profit of €802/ha (Table 4). As prolificacy potential increased from 1.5 to 1.8 lambs weaned per ewe, net profit increased on average by €336/ha, with scenario 6 achieving the greatest increase in net profit. Increasing stocking rate, at 1.5 lambs weaned per ewe joined, increased net profit on average by €15/ha while increasing stocking rate, at 1.8 lambs weaned per ewe joined increased net profit on average by €87/ha. Despite weaning an additional 55 lambs which resulted in an additional €4,860 in lamb receipts, scenario 3 (i.e. 1.5 lambs weaned per ewe, 14 ewes/ha) was less profitable than scenario 2 (i.e. 1.5 lambs weaned per ewe, 12 ewes/ha, Table 4). In general, increasing the number of lambs weaned per hectare increased net profit per hectare but the biggest increase in profitability per hectare was achieved at the higher prolificacy potential.

Maintaining grass growth at 10.07 t DM/ha in the maintained grass growth scenario (i.e. scenario 7), whilst increasing in stocking rate and prolificacy had a negative financial impact, resulting in a negative net profit figure for 14 ewes per hectare at 1.5 and 1.8 lambs weaned per ewe joined. However when weaning rate increases were coupled with stocking rate increases (Table 6) the reduction in profit was less, suggesting that the greater number of lambs weaned allowed the systems to offset the additional cost of the increased purchased feed. The medium stocking rate – low prolificacy potential scenario modelled under scenario 7 had a reduction in net profit of 79%, whereas the medium stocking rate – high prolificacy potential had an 84% reduction in net profit (Table 6). Maintaining grass growth had a greater effect on the low prolificacy scenarios (1.5 lambs weaned per ewe) with the higher stocked of these scenarios severely impacted. The low stocking rate – high prolificacy scenario had the smallest reduction in net profit as there were no additional ewes to be fed when grass was maintained at 10.07 t DM/ha.

3.3 Risk analysis

The impact of varying performance in the key performance variables on mean net profit for each scenario is presented in Figure 1. In general, results from this risk analysis were similar to the deterministic analysis but the greatest absolute mean farm net profit was €13,105 (€655/ha) recorded in scenario 6, whereas scenario 1 had the lowest absolute farm net of profit €5,369 (€268/ha). Across all stocking rates the high prolificacy scenarios (i.e. scenario 4 to 6) were more profitable and had a greater capability to cope with fluctuations in key variables, which resulted in greater mean, maximum and minimum net profit figures (Figure

1). The 90% confidence intervals (5% to 95%) for the high prolificacy scenarios (i.e. scenario 4 to 6) were consistently higher than the low prolificacy scenarios (i.e. scenario 1 to 3), despite having a similar spread in profit (Figure 1), scenario 6 had the greatest spread in farm profit with a 90% confidence interval of €9,067 (€8,029 to €17,096), with scenario 1 having the least spread with a 90% confidence interval of €5,724 (€7,898 to €13,622).

4 Discussion

4.1 Physical

The objective of this study was to provide an economic assessment of future strategies around stocking rate and prolificacy available to grass based sheep production systems. The input data included in this study is based on previous reported research (Earle et al., 2016; Earle et al., 2017) and ensured that each scenario could be modelled with confidence and the use of actual experimental data allowed the author to validate the accuracy of the model outputs with the real farm output data. Nolan (1972), conducted a similar study to Earle et al. (2016, 2017) with low (10 ewes/ha) medium (15 ewe/ha) and high (20 ewes/ha) stocking rates, however, these ewes only weaned 1.27, 1.24 and 0.92 lambs per ewe for the low, medium and high stocking rate scenarios, respectively with the high stocking rate proving too high and severely inhibited flock performance. Earle et al. (2017) showed that although prolificacy potential had no significant effect on lamb lifetime performance, increased stocking rate had a negative effect on lamb growth rates and therefore age to slaughter. In addition the increased carcass output per hectare achieved at the higher prolificacy potentials, ultimately resulting in increased profitability. A previous Australian study has shown that as stocking rate increased, the number of lambs weaned per hectare increased linearly but at the cost of a decline in carcase weight and the numbers of lambs reared per ewe (Reeve and Sharkey, 1980). Similarly other studies have shown that while the overall output per hectare and grass utilisation were increased, the individual output per animal was decreased in dairy (McCarthy et al., 2011; McCarthy et al., 2016; Macdonald et al., 2008) and beef studies (Conway, 1963; Drennan, 1971).

Stocking rate and weaning rate have been described as the two main factors that affect flock productivity, output and profit in Irish grass based sheep production systems (Diskin and McHugh, 2011). In order for the Irish sheep industry to remain competitive, greater grass production and utilisation is required to produce lamb sustainably as grazed grass is the cheapest form of feed on Irish farms (Finneran et al., 2010). Grazed grass and grass silage provide 90 to 95% of energy requirements of a sheep flock (Keady et al., 2009), and as a result the amount of grass produced on farm will decide the optimum stocking rate for that farm. The potential for grass growth varies greatly depending on factors such as meteorological conditions (Keane & Collins 2004; Trnka et al., 2010), soil conditions (Houlbrooke et al., 2011) and general management factors (Garcia-Launay et al., 2012). Recent results from Ireland have shown that irrespective of enterprise (i.e., dairy, beef or sheep) that high grass growth potentials are achievable (Hanrahan et al., 2017). The optimum stocking rate, as defined in this study, is the maximum number of ewes that can be stocked per hectare without introducing high levels of concentrate feed. As highlighted in scenario 7, optimum stocking rate can be determined based on the grass growth potential of the farm. When evaluating the financial and physical performance it is evident that the optimum stocking rate is achieved at approximately 1.1 ewes/ha per t DM/ha grown, weaning 1.5 lambs/ewe joined or 1 ewe/ha per t DM/ha grown, weaning 1.8 lambs per ewe joined, which includes replacements and stock ram grass requirements. A key finding of this study was that, coupled with the number of lambs weaned per hectare, grass growth and utilisation are key to the profitability of a grass based sheep production system corroborating with a previous grass utilisation study (Kennedy et al., 2006). The higher stocking rate scenarios investigated in the current study achieved 90% grass utilisation compared to 85% and 80% in the medium and low stocking rate scenarios, respectively. These utilisation figures are considerably higher than the 60% utilisation figure quoted for the average Irish dairy farm (Läpple et al., 2012). The high, medium and low stocking rate scenarios utilised 12.2 t DM/ha (90%), 10.5 t DM/ha (85%) and 8.7 t DM/ha (80%), respectively, which is significantly higher than the 7.1 t DM/ha achieved by the average Irish dairy farm (Creighton et al., 2011) highlighting that sheep systems have the potential to utilise high levels of grazed grass.

4.2 Financial

At the high prolificacy potential scenarios the efficiency of the system improved due to increased lamb output per hectare, which in turn improved net profit. Scenario 2 and 4 weaned 19 lambs/ha, however scenario 4 achieved a greater net profit because lambs were finished with fewer inputs. Despite weaning an additional 55 lambs compared to scenario 2, scenario 3 had a lower net profit figure (-€20/ha), most likely due to the increased concentrate costs resulting from reduced lamb performance and the lower proportion of lambs finished off a grass only diet. There is a paucity of studies that have quantified the economic impact of alternative stocking rates and prolificacy potentials on the profitability of sheep flocks. Annual survey data collected on Irish farms through the National Farm Survey (Teagasc, 2016b) and the Teagasc e-Profit Monitor system (Teagasc, 2016a) provide an insight into the link between the number of lambs weaned per hectare and overall farm profitability on Irish sheep farms. The 2015 National Farm Survey showed that the top third of sheep farms surveyed weaned 12 lambs/ha compared to 7.5 lambs/ha for the bottom third and this corresponded to a gross margin figure of €912/ha and €162/ha, respectively (Teagasc, 2016b). The 2015 e-Profit monitor found that the average farm was weaning 12 lambs/ha and the top third of farms were weaning 16 lambs/ha resulting in a net profit of €135/ha and

€376/ha, respectively (Teagasc, 2016). These survey results corroborate the findings of this study showing that increasing the number of lambs weaned increases farm profitability. Results from this study also corroborate a previous systems modelling research study in Australia which found that a combined increase in weaning rate and stocking rate resulted in the most profitable system (Jackson et al., 2014). However, the increase in net profit was only achieved if the additional lamb carcass could be produced from predominantly grazed grass. Results from scenario 7 showed that increasing the number of lambs weaned per hectare without increasing grass growth and utilisation proved counterproductive and actually reduced net profit or in the case of the high stocking rate scenarios resulted in a negative net profit. This finding is in agreement with previous studies of Irish dairy systems which concluded that maximum profitability within a grazing system is achieved by increasing grazed grass utilisation through increased growth and better grazing management (Dillon et al., 2008).

The difference in the cost of production per lamb in the low prolificacy scenarios (€75) compared to the high prolificacy scenarios (€65) could be attributed to the higher cost of maintaining more ewes per lamb sold. The additional lambs weaned per ewe also diluted the fixed costs across a greater number of lambs which in turn reduced the cost of production per lamb. Stocking rate did not have a major impact on the cost of production per lamb (Table 5); the slight increase in cost of production for the higher stocking rates is most likely due to increased concentrate usage. Farmers have long been advised that increasing the number of lambs weaned per hectare will increase profitability (Keady and Hanrahan, 2006; Ho et al., 2014), but this study has highlighted that this is only the case when the increased flock output is provided through grazed grass as demonstrated in scenario 7.

4.3 Risk analysis

Monte Carlo simulation, undertaken in the risk analysis in the present study, is highly dependent on the quality of the input data to ensure the quality of the output data (Petersen, 2000). The use of accurate research data from Earle et al. (2016) and (2017) ensured the quality of the risk analysis conducted in this study. The variables used in this study (lamb and mutton price, lamb, replacement and ewe mortality, grass growth, fertiliser and concentrate costs) were chosen due to their variability and their direct impact on net profit (Bohan et al., 2016). The variations in these key inputs have a large impact on the overall output of the system, for example, in a high lamb mortality year, the weaning rate will reduce and in turn the lamb receipts will reduce. Despite a direct reduction in inputs costs due to a reduced number of lambs weaned, many of the overhead costs such as fixed and ewe maintenance costs remain constant. The reduced lamb output resulted in a reduction in overall flock efficiency wilth higher associated production cost per lamb and in turn a reduced net profit. The risk analysis in this study illustrated the distribution in net profit, as well as, the 90% confidence intervals (Figure 1), which highlighted the spread of profit involved in each scenario. This approach demonstrated, for example, that higher stocking rate scenarios and the higher prolificacy scenarios, despite being more profitable, also had greater spread in profit. Scenario 6 had the greatest spread, while scenario 1 had the least. The greater spread associated with the high prolificacy scenarios may be associated with the increased number of lambs in the system resulting in reduced individual animal performance. Despite the risk analysis showing that higher stocking rates and high prolificacy carried slightly greater spread of profit (i.e. greater 90% confidence intervals), this risk is justified as the mean net profit was greater with increased stocking rate and prolificacy potential.

5 Conclusion

The use of the Teagasc Lamb Production Model to assess the economic effect of variation in stocking rate and prolificacy potential in an Irish grass based sheep production system has shown that an increased number of lambs weaned per hectare along with increased grass production and utilisation, increases net profit. Results from this study provide an economic component to previous stocking rate and prolificacy potential studies and provide a starting point to better understand the key drivers of profitability and to allow grass based sheep production systems maximise profit.

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Table 1 Model input assumptions for each scenario included in the Teagasc Lamb Production Model (TLPM)

Scenario*	1	2	3	4	5	6
Farm size (ha)	20	20	20	20	20	20
Ewes joined to the ram	213	256	294	215	259	299
Stocking rate (ewes/ha)	10	12	14	10	12	14
Scanning rate (lambs/ewe)	1.70	1.72	1.80	2.16	2.09	2.11
Weaning rate (lambs/ewe)	1.50	1.50	1.50	1.80	1.80	1.80
Nitrogen use (kg/ha)	113	145	181	113	145	181

*Scenario 1 = 10 ewes/ha, weaning 1.5 lambs per ewe joined, scenario 2 = 12 ewes/ha, weaning 1.5 lambs per ewe joined, scenario 3 = 14 ewes/ha, weaning 1.5 lambs per ewe joined, scenario 4 = 10 ewes/ha, weaning 1.8 lambs per ewe joined, scenario 5 = 12 ewes/ha, weaning 1.8 lambs per ewe joined, scenario 6 = 14 ewes/ha, weaning 1.8 lambs per ewe joined.

Table 2 Comparison of physical details for each scenario including animal numbers, animal performance, feed and labour requirements

Scenario*	1	2	3	4	5	6
Ewes joined to the ram[1]	213	256	294	215	259	299
Lamb mortality (%)[1]	12.64	13.38	17.82	17.67	14.56	15.67
Weaning weight[1]	31.53	32.56	31.34	31.58	28.73	30.47
Lambs weaned	320	385	440	387	468	538
Lambs weaned/ha	16	19	22	19	23	27
Lambs sold/ha	14	17	20	17	20	24
Total carcass sold (kg/ha)	272	327	393	341	403	474
Drafted by October 1st (%)	75	55	47	63	68	50
Total concentrates/ha	456	613	813	552	664	888
Grass Grown (t DM/ha)[1]	10.07	11.61	12.79	11.56	13.01	14.37
Grass utilised (t DM/ha)[1]	8.06	9.87	11.51	9.25	11.07	12.94
Total labour requirement (hrs.)	1201	1442	1681	1201	1442	1683
Total Hired labour (hrs.)	11	74	135	12	74	136

*Scenario 1 = 10 ewes/ha, weaning 1.5 lambs per ewe joined, scenario 2 = 12 ewes/ha, weaning 1.5 lambs per ewe joined, scenario 3 = 14 ewes/ha, weaning 1.5 lambs per ewe joined, scenario 4 = 10 ewes/ha, weaning 1.8 lambs per ewe joined, scenario 5 = 12 ewes/ha, weaning 1.8 lambs per ewe joined, scenario 6 = 14 ewes/ha, weaning 1.8 lambs per ewe joined (Earle et al., 2016; Earle et al., 2017).

[1]Modelled assumptions based on data provided from Earle et al. (2016 & 2017).

Table 3 Minimum, most likely and maximum ranges for the stochastic variables included in the Teagasc Lamb Production Model (TLPM)

Stochastic Variable	Minimum	Most likely	Maximum
Lamb Mortality (singles)	5%	9%	13%
Lamb Mortality (twins)	6%	13%	16%
Lamb Mortality (triplets)	7%	18%	22%
Ewe mortality (annual)	3%	5.5%	7%
Hogget Mortality (annual)	3%	6.5%	8%
Ewe lamb mortality (annual)	0.8%	1.6%	2.4%
Lamb price (€/kg)	2.49 (August)	4.64 (July)	5.86 (May)
Mutton price (€/kg)	1.48 (October)	2.47 (May)	3.30 (March)
Grass growth (KgDM/ha/day)	2 (February)	43 (September)	122 (May)
Concentrate Price (ewes)	€197/T	€310/T	€341/T
Concentrate Price (lambs)	€224/T	€349/T	€397/T
Fertiliser cost (C.A.N)	€190/T	€327/T	€394/T
Fertiliser cost (UREA)	€252/T	€424/T	€454/T
Fertiliser cost (18-6-12)	€235/T	€433T	€507/T
Fertiliser cost (0-7-30)	€206/T	€440/T	€526/T

[*]Scenario 1 = 10 ewes/ha, weaning 1.5 lambs per ewe joined, scenario 2 = 12 ewes/ha, weaning 1.5 lambs per ewe joined, scenario 3 = 14 ewes/ha, weaning 1.5 lambs per ewe

joined, scenario 4 = 10 ewes/ha, weaning 1.8 lambs per ewe joined, scenario 5 = 12 ewes/ha, weaning 1.8 lambs per ewe joined, scenario 6 = 14 ewes/ha, weaning 1.8 lambs per ewe joined.

Table 4 Trading profit and loss accounts for each scenario on a net profit per hectare (€/ha) basis

Scenario*	1	2	3	4	5	6
Wool sales	€52	€64	€70	€53	€65	€74
Lamb sales	€1,299	€1,542	€1,785	€1,607	€1,907	€2,219
Cull sales	€98	€130	€96	€107	€144	€141
Total farm receipts	€1,449	€1,735	€1,951	€1,767	€2,116	€2,434
Variable costs						
Concentrates	€136	€183	€244	€164	€198	€266
Straw	€31	€53	€76	€32	€55	€81
Fertiliser, lime, reseeding	€255	€290	€329	€255	€289	€329
Livestock purchases	€24	€28	€33	€24	€29	€33
Dead animal disposal	€14	€16	€15	€16	€20	€19
Machinery hire	€19	€32	€45	€19	€33	€48
Silage making	€36	€63	€93	€36	€64	€96
Veterinary & medicine	€152	€186	€208	€169	€205	€236
Machinery (R&M)	€94	€94	€94	€94	€94	€94
Total variable costs	€774	€962	€1,155	€825	€1,008	€1,224
Gross margin	€675	€773	€796	€942	€1,107	€1,210
Fixed costs						
Farm vehicle	€84	€84	€84	€84	€84	€84
Electricity & phone	€33	€40	€47	€33	€40	€47

Hired labour	€6	€37	€67	€6	€37	€68
Buildings depreciation	€39	€43	€45	€39	€44	€47
Machinery depreciation	€49	€49	€49	€49	€49	€49
Total fixed costs	€265	€307	€347	€266	€308	€349
Farm net profit	€361	€412	€392	€628	€744	€802

*Scenario 1 = 10 ewes/ha, weaning 1.5 lambs per ewe joined, scenario 2 = 12 ewes/ha, weaning 1.5 lambs per ewe joined, scenario 3 = 14 ewes/ha, weaning 1.5 lambs per ewe joined, scenario 4 = 10 ewes/ha, weaning 1.8 lambs per ewe joined, scenario 5 = 12 ewes/ha, weaning 1.8 lambs per ewe joined, scenario 6 = 14 ewes/ha, weaning 1.8 lambs per ewe joined.

Table 5 Comparison of financial performance of each scenario including number of lambs slaughtered, carcass value, income per lamb, total cost per lamb, net profit per lamb and net profit per kg carcass

Scenario*	1	2	3	4	5	6
Lambs slaughtered	279	335	399	343	410	479
Carcass value	€93.04	€91.95	€89.42	€93.80	€93.10	€92.57
Total income per lamb	€103.84	€103.48	€97.74	103.16	€103.30	€101.56
Concentrate costs per lamb	€9.72	€10.91	€12.20	€9.60	€9.66	€11.10
Cost of production per lamb	€74.46	€75.69	€75.24	€63.65	€64.29	€65.65
Net profit per lamb	€25.89	€24.56	€19.64	€36.64	36.33	€33.45
Price received per kg	€4.78	€4.72	€4.55	€4.71	€4.73	€4.68
Cost of production per kg	€3.83	€3.88	€3.83	€3.20	€3.27	€3.32
Net profit per kg	€1.33	€1.26	€1.00	€1.84	€1.85	€1.69

*Scenario 1 = 10 ewes/ha, weaning 1.5 lambs per ewe joined, scenario 2 = 12 ewes/ha, weaning 1.5 lambs per ewe joined, scenario 3 = 14 ewes/ha, weaning 1.5 lambs per ewe joined, scenario 4 = 10 ewes/ha, weaning 1.8 lambs per ewe joined, scenario 5 = 12 ewes/ha, weaning 1.8 lambs per ewe joined, scenario 6 = 14 ewes/ha, weaning 1.8 lambs per ewe joined.

Table 6 Total net profit for scenario 1 to 6 when grass growth and utilisation increased with flock demand (Net Profit) and when grass growth and utilisation were maintained regardless of demand (Scenario 7 net profit)

Scenario*	1	2	3	4	5	6
Net profit	€7,228	€8,236	€7,842	€12,554	€14,879	€16,034
Scenario 7 net profit	€7,228	€1,730	-€3,471	€6,403	€2,381	-€2,565
Reduction in net profit	0%	-79%	-150%	-49%	-84%	-116%

*Scenario 1 = 10 ewes/ha, weaning 1.5 lambs per ewe joined, scenario 2 = 12 ewes/ha, weaning 1.5 lambs per ewe joined, scenario 3 = 14 ewes/ha, weaning 1.5 lambs per ewe joined, scenario 4 = 10 ewes/ha, weaning 1.8 lambs per ewe joined, scenario 5 = 12 ewes/ha, weaning 1.8 lambs per ewe joined, scenario 6 = 14 ewes/ha, weaning 1.8 lambs per ewe joined.

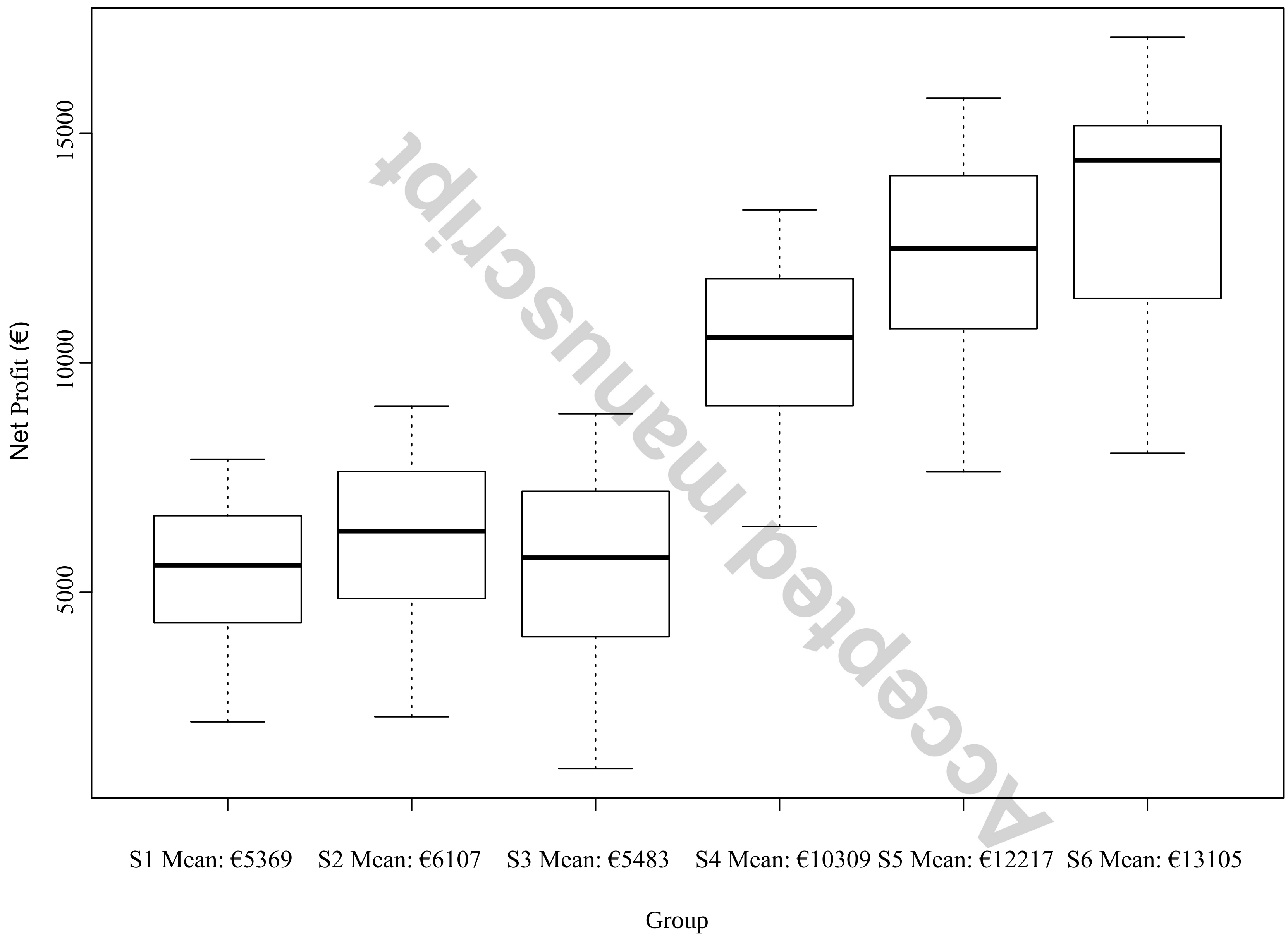

Figure 1. Box and whisker plot of the mean farm net profit, 5th and 95th percentile, as well as, the interquartile ranges of each scenario.

Highlights

- Stocking rate and ewe prolificacy along with increased grass growth and utilisation are the key drivers of profit.
- Increasing the number of lambs weaned per hectare reduces the cost of production per lamb and in turn increases profit.
- Increasing the number of lambs weaned per hectare without increasing grass growth and utilisation is counterproductive.