DOCTOR OF PHILOSOPHY

Effect of Lolium perenne L. ploidy, Trifolium repens L. inclusion and cow breed on the productivity and profitability of pasture-based, spring-milk systems

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Effect of *Lolium perenne* L. ploidy, *Trifolium repens* L. inclusion and cow breed on the productivity and profitability of pasture-based, spring-milk systems

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Abstract

With the recent abolition of milk quotas in the European Union, there has been a large increase in milk production in Ireland driven by an increase in cow numbers and milk yield per cow. Dairy production systems in Ireland are primarily pasture-based and factors such as sward type and cow genotype can affect the efficiency and profitability of these systems. Pasture-based production systems typically require highly fertile, healthy and robust cows with greater emphasis on milk solids production as opposed to milk yield. The aim of this study was to assess the productivity of three cow genotypes when grazing tetraploid or diploid perennial ryegrass (*Lolium perenne* L.; PRG) sown with and without white clover (*Trifolium repens* L.). Four grazing treatments were compared for this study; tetraploid PRG-only swards, diploid PRG-only swards, tetraploid PRG with white clover swards and diploid PRG with white clover swards. Three cow genotypes were analysed; Holstein-Friesian (HF), Jersey × HF (JEX) and a 3-way cross consisting of 50% Norwegian Red, 25% Jersey and 25% HF (3WAY). Thirty cows (ten of each genotype) were assigned to each grazing treatment and swards were rotationally grazed after calving in spring at a stocking rate of 2.75 cows/ha and a nitrogen fertiliser rate of 250 kg/ha annually over four years (2014 to 2017). Milk production did not differ between the two ploidies over this four year study, but cows grazing the PRG-white clover treatments had significantly greater milk yields (+ 596 kg/cow per year) and milk solid (kg fat + protein; MS) yields (+ 48 kg/cow per year) compared with cows grazing the PRG-only treatments, resulting in increased milk (+ 1,954 kg/ha) and MS (+ 156 kg/ha) yields per ha. Ploidy did not affect the white clover content of the swards, with swards having an average white clover content of 23% over the four years. The PRG-white clover swards also produced an additional 1,205 kg DM/ha herbage on average over the four year period. This additional herbage was harvested in summer and used in spring when there was lower pasture availability on PRG-white clover swards due to lower overwinter growth compared to PRG-only swards. Holstein-Friesian cows produced higher total milk yields compared to JEX and 3WAY cows (5,718 vs. 5,476 and 5,365 kg/cow, respectively; \( P < 0.001 \)). However, JEX and 3WAY had higher milk fat and protein content (4.86% and 4.75% and 3.87% and 3.88%, respectively) compared to HF (4.52% and 3.72%; \( P < 0.001 \)), resulting in similar MS yield for JEX and HF, (469 and 460 kg/cow) and slightly lower \( (P = 0.003) \) MS from 3WAY (453 kg/cow) compared to JEX. Reproductive performance did not differ significantly between the three genotypes with similar 24 day submission rates, six-week pregnancy rates and overall pregnancy rates. Bodyweight (BW)
was significantly different \((P < 0.001)\) between all three genotypes with HF being the heaviest followed by 3WAY and JEX (530, 499 and 478 kg, respectively) and 3WAY cows had a higher body condition score throughout lactation \((P < 0.001)\) compared to HF and JEX. Perennial ryegrass ploidy had no impact on dry-matter intake (DMI) however, significant increases in DMI \(+0.5 \text{ kg DM/cow per day}\) were observed from cows grazing PRG-white clover swards compared to PRG-only swards. Dry-matter intakes differed significantly between genotypes \((17.2, 17.0 \text{ and } 16.7 \text{ kg DM/cow per day for } \text{HF, JEX and 3WAY cows, respectively})\) which consequently affected production efficiencies. Jersey x Holstein-Friesian had the greatest total DMI/100 kg BW \((3.63 \text{ kg})\), 3WAY were intermediate \((3.45 \text{ kg})\) and HF were lowest \((3.36 \text{ kg})\). The above biological results supplied data for modelling the economic performance of six different production systems (two sward types (PRG-only and PRG-white clover) with three genotypes (HF, JEX and 3WAY)) using the Moorepark Dairy Systems Model (stochastic budgetary simulation model). The analysis showed that adding white clover to the PRG swards increased profitability by €305/ha in a fixed land scenario with a milk price of 29c/l, across cow genotype. In the same fixed land scenario, JEX cows were most profitable \((€2,606/ha)\), followed by 3WAY \((€2,492/ha)\) and HF \((€2,468/ha)\). The system that produced the highest net profit was JEX cows grazing PRG-white clover swards \((€2,751/ha)\). Although white clover is generally used in combination with reduced nitrogen fertiliser use, this thesis provides evidence that including white clover in either tetraploid or diploid PRG swards, combined with high levels of nitrogen fertiliser can be effectively managed to increase milk production per cow and per ha, however the environmental impacts and the persistency of white clover require further investigation. This thesis also showed that all three genotypes were suitable for spring-calving, pasture-based milk production systems as they had similar MS production, reproductive performance and functional traits however, there are still production efficiency benefits to be gained from crossbreeding.
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ADF = acid detergent fibre
AFC = average farm cover
AI = artificial insemination
BCS = body condition score
BNF = biological nitrogen fixation
BW = bodyweight
CAN = Calcium ammonium nitrate
CAP = common agricultural policy
CP = crude protein
cm = centimetre
CSO = central statistics office
DAFM = Department of Agriculture, Food and Marine
DHA = daily herbage allowance
DIM = days in milk
DM = dry-matter
DMI = dry-matter intake
DGO = diploid PRG-only
DWC = diploid perennial ryegrass with white clover
EBI = economic breeding index
EU = European union
FAO = Food and Agriculture Organisation of the United Nations
FCE = feed conversion efficiency
FVI = forage value index
g = gram
GC = Perennial ryegrass with white clover
GHG = Greenhouse gases

GO = Perennial ryegrass-only

ha = hectare

HF = Holstein Friesian

ICBF = Irish Cattle Breeding Federation

JEX = Jersey x Holstein Friesian

K = potassium

Kg = kilogram

LU = livestock unit

m = metre

ME = metabolisable energy

MDSM = Moorepark dairy systems model

mm = millimetre

MS = milk solids

N = nitrogen

NDF = neutral detergent fibre

NE = net energy

NFS = national farm survey

NR = Norwegian Red

NS = non-significant

NZ = New Zealand

OM = organic matter

OMD = organic matter digestibility

P = phosphorous

PBI = PastureBase Ireland

PDMI = pasture dry-matter intake

PoGSH = Post grazing sward height
PrGSH = Pre-grazing sward height
PrGHM = Pre-grazing herbage mass
PPI = Pasture Profit Index
PRG = perennial ryegrass
PTA = predicted transmitting ability
S.E. = standard error
SCC = somatic cell count
SCM = solids corrected milk
SR = stocking rate
t = tonne
TDMI = total dry-matter intake
TWC = Tetraploid PRG with white clover
TMR = total mixed ration
TGO = Tetraploid PRG-only
UFL = Unité fourragère lait
UK = United Kingdom
USA = United States of America
WSC = Water soluble carbohydrate
3WAY = 3-way rotational cross; 50% Norwegian Red, 25% Jersey and 25% Holstein Friesian
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Chapter 1
General Introduction

Prior to 2015, European Union (EU) milk quotas were the main factor limiting farmers’ opportunity to increase production. Since the abolition of those milk quotas, Ireland has significantly increased its milk production (Läpple and Sirr, 2019), but now the main limiting factor for expansion is the availability of land. Farm sizes are traditionally small in Ireland; in 2000 average herd size was circa 50 cows, but since quota abolition average dairy herd size has increased to approximately 79 cows (CSO, 2019). With the availability of land now a critical factor, stocking rates on existing farms are rising in order to increase output per unit of land. Therefore, the efficiency of grass utilisation is particularly important for pasture-based dairy production in Ireland. Additionally, pasture-based systems are regarded as a good basis for economical and stable milk production in volatile global markets, due to their low costs compared to confinement and high output systems (Shalloo et al., 2004c; O’Brien et al., 2012; Fariña and Chilibroste, 2019). Pasture production and grazing efficiency are therefore key performance indicators of profitability in pasture-based systems (Macdonald et al., 2017; Hanrahan et al., 2018). Environmental concerns and regulations must also be considered with water quality and climate change an increasing concern, and agriculture in particular being a major source of nutrient losses and greenhouse gas (GHG) emissions. Chemical nitrogen (N) use for agriculture in Ireland is currently restricted under the Nitrates directive (European Commission, 2019). The Nitrates directive restricts chemical N application to a maximum of 170 kg N/hectare (ha) per year or up to 250 kg N/ha per year under derogation. Derogation allows farms that are stocked higher to apply more chemical N; however these farms are also subject to additional environmental conditions such as the use of low emission slurry spreading equipment and regulations on application times. Almost 7,000 farms in Ireland availed of derogation in 2018 with the majority being in the south and east of the country. It is within the context of the current challenges for dairy farming to optimise the use of grassland resources, that the studies within this thesis were conceived. The general context for each of the research chapters was as follows.

The environmental regulations along with increasing fertiliser prices since 2000 has resulted in an increased interest in white clover (Trifolium repens L.) for grazing swards and red
clover (*Trifolium pratense* L.) for silage swards (Burchill et al., 2014; Dhamala et al., 2016; Lüscher et al., 2014). Both red and white clover have the ability to biologically fix atmospheric N, with red clover having a lower sward persistence and more upright growth making it less suitable for grazing (Rasmussen et al., 2012). Furthermore, previous studies have shown improvements in animal performance for cows grazing different perennial ryegrass (*Lolium perenne* L.; PRG) ploidies (Gowen et al., 2003, Wims et al., 2013) and when white clover is included in grazing swards (Harris et al., 1997; Ribeiro Filho et al., 2003; Egan et al., 2018). It has also been hypothesized that there may be an interaction between PRG ploidy and white clover content, attributed to tetraploid swards having a lower sward density than diploids and thus providing less competition with white clover (Gooding et al., 1996, Stewart and Hayes, 2011). Chapter four, therefore investigated the milk production potential of cows grazing swards differing in PRG ploidy and white clover inclusion.

The objective of pasture-based systems in Ireland is to increase farm profitability per ha by implementing practices that increase the amount of grass utilised and milk solids (kg fat + protein; MS) produced per ha while also improving nutrient use efficiency. Pasture-based systems also require the right animal to suit this type of system where cows must calve within a short period in spring, walk longer distances compared to housed animals and produce high quality milk from grazed herbage (O'Donovan et al., 2011). Successful grazing requires animals with the capability to achieve large intakes of forage to meet productive potential and an ability to adapt to a fluctuating feed supply (Dillon, 2007). This system also requires animals to calve compactly in spring to maximise days at grass and thus milk produced from grazed forage. In Ireland, spring calving pasture-based dairy production systems predominate and 90% of dairy cows are Holstein-Friesian (HF; DAFM, 2018). There has been a historical decline in reproductive performance of HF cows which has since been linked to selection based mainly on milk production (Lucy, 2001; Dillon et al., 2003). Consequently, current breeding strategies now place greater emphasis on functional traits (mainly reproduction and health), which has generally halted the decline in reproductive performance (Miglior, et al., 2017; Cole and Van Raden, 2018; Lucy, 2019). Crossbreeding has also been proposed as an alternative breeding strategy to provide a “better balance” and produce robust animals due to a combination of breed complementarity and heterosis (Delaby et al., 2018). Chapter five compared three cow genotypes for milk production, reproductive performance and functional
traits in a spring-calving pasture-based system. The three cow genotypes were HF, Jersey x HF (JEX) and JEX x Norwegian Red (3WAY). As mentioned, the more modern HF in Ireland has been bred with greater emphasis placed on functional traits and fertility; therefore it was important to compare them to F1 crossbred animals from Jersey bulls (the most common crossbred cow used in pasture-based systems). The 3WAY breed was included to investigate the effect of introducing a third breed in a 3-way rotational breeding system and whether this introduced any favourable traits or would have comparable performance to the previous two genotypes. The theoretical advantages of a three-breed rotational crossing system have been previously highlighted with the maximisation of hybrid vigour (Lopez-Villalobos et al., 2000). However, there is a knowledge gap in three-breed rotational crossing with very few studies undertaken previously.

Milk production from pasture is limited by the ability of the grazing animal to consume sufficient quantities of herbage (Stakelum and Dillon, 2003). Balocchi and Lopez (2010) showed cows grazing diploid and tetraploid PRG swards had a preference to graze tetraploid swards, illustrated by a higher utilisation rate and lower post-grazing residual for tetraploid swards. This may infer a relationship between grazing preference and dry-matter intake (DMI), with animals voluntarily grazing for longer and lower into the sward (Gowen et al., 2003). This grazing preference may be linked to physical (more erect growth and larger tiller size; Tozer et al., 2014) and nutritional (higher DMD and water soluble carbohydrate content; Smith et al., 2001) differences between tetraploids and diploids. White clover has also been shown to be grazed preferentially over PRG and increase DMI (Rutter et al., 2004; Egan et al., 2018). This preference has been linked to a faster rumen passage rate of white clover compared to PRG due to its lower NDF and ADF content (Minson, 1990; Egan et al., 2018). Studies in Ireland by Kennedy et al. (2003) and Horan et al. (2005b) observed Holstein cows highly selected for milk volume were not capable of eating enough to satisfy the demand associated with their milk potential. Increased pasture allowance induces higher levels of pasture DMI but also higher levels of refusals and decreases pasture utilisation (Delaby and Horan, 2017). Therefore, a balance must be achieved between pasture and animal performance. With this as an objective, Chapter six investigated the effect of sward type (PRG ploidy and white clover inclusion) and cow genotype on dry-matter intake (DMI) and production efficiencies at pasture.
The efficiency and profitability of pasture-based systems are impacted by a number of factors such as pasture production and utilisation (Hanrahan et al., 2018), soil type (Shalloo et al., 2004a), stocking rate (Macdonald et al., 2008), grazing season length (Läpple et al., 2012b) and supplementary feed use (Ramsbottom et al., 2015; Macdonald et al., 2017; Hanrahan et al., 2018). However, it is acknowledged that pasture use (Hanrahan et al., 2018; Ramsbottom et al., 2015) and cow genotype (McCarthy et al., 2007; Prendiville et al., 2011b) are two of the main factors that affect profitability within pasture-based dairy production systems. Therefore, in Chapter seven the economic performance of two sward types (PRG with or without white clover), grazed by the three different cow genotypes (HF, JEX and 3WAY) was evaluated using the Moorepark Dairy Systems Model (MDSM; Shalloo et al., 2004b). The profitability of sward type and cow genotype were analysed under differing scenarios where land area was fixed, which is reflective of the situation on most Irish farms, as well as where cow numbers are fixed which could be reflective of potential future restrictions at farm level.

The combined aim of the studies completed in this thesis was to evaluate which sward type along with which cow genotype would be the most productive and profitable in spring-calving milk production systems, and if there were any interactions between sward type and cow genotype that could be exploited to an advantage for Irish dairy farming.
Chapter 2
Literature Review

2.1 Introduction

This literature review will use the most relevant and recent literature available to provide an overview of previous research on the effect of sward type and cow genotype on the productivity of dairy systems. Detail will be provided on the effect of grazing tetraploid versus diploid perennial ryegrass (*Lolium perenne* L.; PRG) swards and the inclusion of white clover (*Trifolium repens* L.) in swards on pasture production, nutritive value and animal performance. The effect of crossbreeding and cow genotype on animal performance in terms of reproduction, dry-matter intake (DMI), production efficiency and economic performance will also be reviewed.

2.2 Grassland in Temperate Regions

2.2.1 Global context of pasture-based systems

There are numerous benefits to pasture-based systems compared to the more common indoor feeding systems. Many studies have found pasture-based systems to be more sustainable (financially and environmentally) with grazing dairy cows converting non-human edible protein into high quality dairy products (O’Brien et al., 2012). There are also benefits based on consumer perceptions of the dairy industry that grazing systems are more sustainable, and have higher animal welfare, while producing high quality dairy products (Dillon et al., 2005; Peyraud et al., 2010). This favourable consumer perception of grass-based systems has encouraged some processors to offer a premium for milk produced from cows that have access to pasture for grazing, this then allows the processor to charge a premium price to the consumer and offer a point of differentiation in the market (Elgersma, 2012; Van den Pol-van Dasselaar et al., 2018). There is increasing interest in pasture-based systems due to their ease of establishment and lower requirement for capital infrastructure, low operating expenses per kg of milk, and potential access to high-value markets because of perceived animal welfare benefits (Roche et al., 2017). This has subsequently led to a range of grazing systems being developed globally. Typical dairy grazing systems are designed to grow large yields of digestible forage, generally grass-legume mixtures, and harvest a high proportion of the
pasture grazed directly by the cow. This involves numerous factors such as (1) optimal soil fertility and appropriate fertiliser use; (2) matching the feed demand of the herd with the annual pasture supply (using strategic decisions around calving date and stocking rate); and (3) having the correct farm infrastructure of paddocks and roadways to facilitate easy access to pasture (Macdonald et al., 2017; Roche et al., 2017). Although the findings in this thesis have relevance for temperate dairy farming in many parts of the world, the research having been conducted in Ireland is particularly applicable to the Irish dairy industry. Therefore, a more detailed explanation of the growing conditions and practices in Ireland is presented.

2.2.2 Ireland's climate

The Irish climate is classified as temperate maritime and is modified by the North Atlantic current and the Gulf Stream. Ireland typically has mild winters, cool summers and is consistently humid with an average annual rainfall of between 750 mm/year in the east of Ireland and 1,400 mm/year in the west of Ireland (Met Eireann, 2019). Averaged over all Ireland, annual rainfall is approximately 1,230 mm. The driest seasons are spring and summer, with an average rainfall of approximately 260 mm, whereas autumn and winter have rainfall averages of approximately 350 mm. The driest months are April, May, June and July, with an average of approximately 80 mm rainfall each month. February, March, August and September have average rainfall totals of approximately 100 mm, while October, November, December and January have rainfall averages of approximately 130 mm (Met Eireann, 2019).

The temperature regime in Ireland is greatly affected by the moderating effect of the sea, and height above sea level. Mean annual temperatures generally range between 9°C and 10°C with the higher values in coastal regions. Summer is the warmest season, followed by autumn, spring and winter. Highest temperatures occur inland during the summer, with mean seasonal maxima between 18°C and 20°C while highest values occur in coastal regions during the winter. July is the warmest month, followed by August and June; the coldest month is January followed closely by February and then December.

2.2.3 Grassland in Ireland

Meteorological factors such as soil moisture, soil temperature and solar radiation levels have a large impact on pasture-based production systems in temperate regions, as grass growth
varies substantially with the somewhat unpredictable annual and seasonal weather patterns (Norris, 1985; Parsons, 1988; Hurtado et al., 2013). Fortunately, Ireland does not typically experience seasonal climatic extremes compared to countries at similar latitude levels, due to the Atlantic Ocean coast and the impact of the Gulf Stream (Met Eireann, 2019), although there is still a large year to year variation in climate dependent grass growth. There is a long growing season which can be up to 300 grass growing days in length in the most favourable parts of the country (O’Donovan et al., 2011). O’Donovan et al. (2011) stated that Ireland has the potential to grow between 12-16 t DM/ha of grass and this has been supported by recent data from PastureBase Ireland (Hanrahan et al., 2017) showing a large range in grass growth across the country (Figure 2.1) with an average grass growth of 14.4 t DM/ha in 2017 and 11.0 t DM/ha in 2018 (PastureBase, 2019). The reduced grass growth in 2018 was due to a period of severe drought during the summer, which is typically rare in Ireland, and had a negative impact on the national grass growth curve (Figure 2.2). Periods of prolonged rainfall can require animals to be housed to prevent damaging paddocks during the grazing season and intensive dairy farms must have adequate facilities for housing of cattle, and storage facilities for the manure produced over the winter period as outlined under the Nitrates Directive (European Commission, 2019).
Figure 2.1 Annual pasture production of dairy farms throughout Ireland in 2017 (t DM/ha) from PastureBase Ireland
Figure 2.2 National grass growth curve showing the five year average, 2018 and early 2019. 
Source: Pasturebase Ireland

2.3 Dairy Production

In the last three decades, world milk production has increased by more than 58%, from 522 million tonnes in 1987 to 828 million tonnes in 2017 (FAO, 2019). Most of this expansion in milk production has been in South Asia, which is the main driver of milk production growth in the developing world. India is the world’s largest milk producer, with 21% of global production, followed by the United States of America, China, Pakistan and Brazil (FAO, 2019). The countries with the highest milk surpluses are New Zealand, the United States of America, Germany, France, Australia and Ireland. It is estimated that more than 90% of the world’s milk supply is produced in mixed farming systems, where animal feed comes from arable crops (FAO, 2019). Many dairy farmers avoid using pasture systems because milk production per cow is lower compared to confinement total mixed ration (TMR) feeding systems (Kolver and Muller, 1998; White et al., 2002). Some management challenges when pasture is the only forage include low milk production per cow, low milk fat and protein
content, variations in production because of climate conditions, difficulty in budgeting pasture availability, and inaccurate estimation of total and pasture DMI (Bargo et al., 2002). However, there are benefits to pasture-based systems compared to the globally more common confinement feeding system as many studies have found pasture-based systems to be more sustainable (financially and environmentally) with grazing dairy cows converting non-human edible protein into high quality dairy products (Ferris, 2007; Acosta-Alba et al., 2012; O’Brien et al., 2014). There are also benefits based on consumer perceptions of the dairy industry that grazing systems are more sustainable, have higher animal welfare and produce higher quality dairy products (Dillon et al., 2005; Peyraud et al., 2010). Reduced feed, waste management and labour costs are also associated with pasture-based systems (Heinschink et al., 2016).

2.3.1 Milk production in Ireland

Ireland has a land area of approximately 6.9 million ha, and of this a total of 4.47 million ha are used for agricultural purposes. Of the total area farmed, primary pasture accounts for 48.7% use while primary silage and hay production accounts for 31.7%, which means forage systems comprised primarily of grass makes up 80% of farmed land in Ireland (CSO, 2017; O’Brien et al., 2018). There are approximately 15,600 dairy farmers in the country with an average farm having 75 cows on 56 ha (National Farm Survey, 2017). The average milk produced was 5,397 litres/cow and 402 kg/cow milk solids (kg fat + protein; MS) from 1,032 kg concentrate with an average grazing season length of 235 days per year (National Farm Survey, 2017). The majority of farms in Ireland are spring-calving, pasture-based systems where cows calve from early February onwards to match herd demand with pasture growth throughout the year (Figure 2.3; Connolly et al., 2010). Spring milk production accounts for about 90% of total milk produced and is characterised by a seasonal production system with a high proportion of grazed grass in the diet. Supplement concentrate feeding is ideally kept to a minimum, largely when grass growth is insufficient to support animal demand in the margins of the growing season or over winter, to optimise efficiency of use and control production costs (Figure 2.3; Dillon et al., 1995; Kennedy et al., 2008; Finneran et al., 2010). Figure 2.4 shows the seasonal supply of milk to Irish processors for the last five years, with supply peaking in May and the lowest supply in December and January. It also illustrates the steady increase in milk supplied each year since the abolition of European Union (EU) milk
Figure 2.5 and 2.6 show the trends in milk fat and protein content throughout the year. Milk fat typically declines during the summer months but steadily increases thereafter. Milk protein is quite stable for the first half of the year and then rises in autumn.

Figure 2.3 Profile of herd feed demand compared to grass growth and key time points (i.e. calving, breeding and drying off) for a spring calving herd (adapted from Holmes et al., 2002)
Figure 2.4 Milk supplied to Irish milk processors each month from 2014-2018 (CSO, 2019)

Figure 2.5 Fat content of milk supplied to Irish milk processors each month from 2014-2018 (CSO, 2019)
Over 90% of the milk produced in Ireland is exported in the form of dairy products to over 130 countries across the globe. The largest Irish export volume growth in 2018 was in the dairy sector, with export volumes up 5% compared to 2017 and the value of dairy exports exceeding €4 billion for the second year in a row. In 2018 the value of Irish butter exports exceeded €1 billion for the first time (mainly due to USA and European demand), a 22% increase on 2017’s value (Figure 2.7; Bord Bia, 2019). The North American market grew by 36% in 2018 to be valued at €366 million. North America’s butter exports increased by 90% to €161 million, along with the value of cheese exports growing by 20% in 2018. Exports to continental Europe were valued at €1.35 billion, a 6% increase on 2017. Exports to the United Kingdom (UK) were valued at €1.03 billion which was also a 6% growth on 2017 values (BordBia, 2019). The UK remains a key market accounting for around a quarter of total Irish dairy exports (Figure 2.7), which may cause concern in the future due to its current intention to withdraw from the EU (Brexit). There is also significant cross-border milk processing between the Republic of Ireland and Northern Ireland which is in the UK. Therefore, this is currently a cause of great concern with the threat of a ‘hard Brexit’

Figure 2.6 Protein content of milk supplied to Irish milk processors each month from 2014-2018 (CSO, 2019)
occurring, that might impose trade tariffs and regulatory impediments to a free flow of goods between both territories (Tonge, 2016).

Figure 2.7 Destination of Irish dairy exports in 2017 and 2018 (Source: BordBia, 2019)

2.3.2 Milk quotas

The European Common Agricultural Policy (CAP) set up in 1957 aimed to guarantee food security in post-war Europe and ensure stable and reasonable prices for consumers by incentivising production and protecting domestic agriculture from foreign competitors (Whetstone, 1999). In terms of dairying within the EU this led to a huge increase in milk production and caused market surpluses equal to 30% of the overall CAP budget by 1983 (Dillon et al., 2008). European Union milk quotas were introduced in 1984 as one of the tools to help overcome the issue of surplus production. Changes to the EU's CAP have increased the market-orientation of the dairy sector and provide more targeted payments to help support producers in vulnerable areas, where costs of production can be higher. In 2003, the Luxemburg Agreement proposed that EU milk quotas should be removed by 2015 to allow producers more flexibility to respond to growing demand, especially on the world market (Läpple and Hennessy, 2012a). The abolition of EU milk quotas has undoubtedly facilitated expansion on many dairy farms in Ireland and across the EU; it has also posed challenges in terms of increased investment at farm level within a volatile milk price environment. In the year following quota abolition, milk production increased by 4.5% in the EU. However, due
to production advantages, milk supply responses varied considerably across EU Member States, for example, Ireland increased its milk production by 18.5% while Italy reduced its milk production (Läpple and Sirr, 2019). By 2018 milk production in Ireland had increased by over 50% since the removal of milk quotas in 2015 (Läpple and Sirr, 2019). The large increase in milk production in Ireland has been driven by an increase in new entrants to dairy farming, an increase in cow numbers on existing dairy farms and an increase in milk yield per cow (Läpple and Sirr, 2019). Volatile market prices for both costs of production and milk price, particularly leading up to and since the abolition of milk quotas, highlights the question whether a high or low input milk production system will best maximise long term profitability. Low-input pasture-based systems have clearly been shown to be more resilient in volatile world dairy markets (Dillon et al., 2008; Macdonald et al., 2017). While Ireland is one of the lowest cost milk producers worldwide as shown in Figure 2.8 we only contribute about 4% of EU milk production. However, it has been hypothesised that milk production will further concentrate in regions with a comparative advantage and some argue that milk production will predominately move into regions with a temperate climate and high grass growth such as Ireland and the UK (Donnellan et al., 2015).

![Figure 2.8](image.png)

**Figure 2.8** Relationship between total cost of production and percentage of grass in dairy cows diet. Source: Dillon et al. 2005
2.3.3 Pasture-based grazing systems

As discussed previously, in contrast to most of continental Europe and the USA, where milk is produced from TMR diets in confinement systems (Dillon et al., 2005), in Ireland milk is mainly produced from pasture-based systems. Pasture-based systems are more economically competitive than TMR systems (Hanson et al., 1998; Dartt et al., 1999; Shalloo et al., 2004c). Grazed grass is the most cost effective feed available to all ruminant livestock production systems with a relative cost ratio of grazed grass to grass silage to concentrate of 1:1.8:2.4 (Finneran et al., 2010; O'Donovan and Delaby, 2016). A 10% increase in the percentage of grazed grass as a proportion of the overall diet of a dairy cow has been shown to reduce the cost of milk production by 2.5 c/l (Dillon et al., 2005; Figure 2.8). Nationally, it is estimated that the average dairy farm utilises 7.1 tonne of grass DM/ha (Creighton et al., 2011), while more efficient farms are growing and utilising in excess of 12–14 tonnes of grass DM/ha over a 280 day grazing season with stocking rates of over three cows/ha (Shalloo et al., 2011). A huge range of variables can affect pasture growth such as soil type, climate and region, soil fertility, reseeding frequency and grazing management (Norris, 1985; Parsons, 1988; Shalloo et al., 2004a; Shalloo et al., 2011). Several farm profitability studies have associated many pasture management and production traits such as overall pasture use, grazing season length, and overall pasture management with lowered production costs (Macdonald et al., 2010; Shalloo et al., 2011; Läpple and Hennessy, 2012a; Ramsbottom et al., 2015). A recent study in Ireland has shown that approximately 42% of the variation in total profit per ha can be explained by pasture utilisation per ha and each additional tonne utilised can increase net profit by an estimated €173 per ha (Hanrahan et al., 2018). Therefore, the production and utilisation of pasture has a central role in maintaining the competitiveness of the Irish dairy industry.

2.4 Perennial Ryegrass

2.4.1 Role in grazing systems

Perennial ryegrass is the most widely sown grass species in temperate grazing systems worldwide and in Ireland accounts for approximately 95% of forage grass seed sold (Drennan et al., 2005). Based on the sales of grass seed, it is estimated that approximately 2% of the land area on farms in Ireland is reseeded annually (DAFF, 2009). Perennial ryegrass is used in temperate grazing systems because it has a high yield potential, establishes quickly, is
highly palatable and digestible for ruminants and is tolerant of intensive grazing systems (Wilkins, 1991; Waghorn and Clark, 2004). Perennial ryegrass is most suited to cool, moist climates where winter frosts are not severe and grows best on fertile, well-drained soil but has a wide range of soil adaptability (Hannaway et al., 1999). Current PRG evaluations are mainly focused on herbage yield as determined by mechanically harvesting cultivar plots. However, these evaluations put little emphasis on herbage utilisation, which is a difficult trait to evaluate on plot trials without the use of grazing animals. Post-grazing sward height is routinely reported as an indicator of grazing efficiency (O’Donovan and Delaby, 2005; McCarthy et al., 2013). Certain PRG cultivars that can be consistently grazed to a residual height of 3.5–4.0 cm have been associated with a higher content of green leaf and digestible nutrients, whilst having reduced stem and senescent material (Tuñon et al., 2014; Tubritt et al., 2018). In grazing swards, PRG cultivars are generally used in seed mixtures as a combination of tetraploids and diploids, with less of a preference for hybrid cultivars due to their lack of persistence over time.

2.4.2 Morphology

Perennial ryegrass establishes rapidly from seed, has a strong tillering capacity, produces a dense sward, is palatable to stock, is capable of withstanding intensive grazing, responds well to inputs of nitrogen (N), and is capable of surviving in well managed pastures over a long period (10 years +; Wilkins, 1991) Perennial ryegrass is generally termed a ‘three leaf plant’ because each tiller sustains a maximum of three live fully expanded leaves (Moore et al., 1991; Figure 2.9). There is always only one leaf growing on each tiller at any time, when the next leaf appears, the previous leaf has stopped growing and if not defoliated will in turn senesce. Perennial ryegrass grows best in the range 5°-18°C, in ideal conditions a new leaf may grow every 8 days (Wilkins, 1991). Reproduction is mainly through daughter tillers which become independent from the parent tiller and result in a new plant (Moore et al., 1991). Tillering is greatest after sowing with each tiller lasting for one year and dying after turning reproductive. Perennial ryegrass flowering results from a physiological change at the stem apex, which produces a seed head but no further leaves, and eventually results in the tiller death (Hunt and Field, 1979). This phenomenon and other environmental changes result in marked seasonal trends which impact growth rates and pasture nutritive value (Hurley et al., 2008; Beecher et al., 2015). During the reproductive stage, there is a proportionally lower
leaf and higher stem content than during the vegetative stage, and so swards are less digestible during the reproductive stage than during the vegetative stage (Beecher et al., 2015).

Figure 2.9 Growth phases of perennial ryegrass tillers Source: DairyNZ

2.4.3 Perennial ryegrass ploidy

In its natural form PRG is a diploid (2x) but in 1939 the creation of a tetraploid (4x) PRG was reported (Myers, 1939). The duplication of the number of PRG chromosomes generates a series of morphological and physiological changes in tetraploid plants associated with an increase in cell size, increasing the cell content/cell wall ratio (Myers, 1939). This increase in the proportion of cellular content increases the concentration of soluble carbohydrates, proteins and lipids, and increases digestibility (Smith et al., 2001). However, this also contributes to a lower dry-matter (DM) content in tetraploid compared to diploid cultivars (O’Donovan and Delaby, 2005; Byrne et al., 2017). There are also significant differences between tetraploid and diploid cultivars in physical appearance and performance. Tetraploid seed is typically larger compared to diploid seed and is quicker to establish plants, but requires a higher sowing rate to have similar plant numbers (Castle and Watson, 1971).
Tetraploid swards are usually less dense than diploid swards but have larger tillers (Tozer et al., 2014). There are large genetic variations between PRG cultivars that have been shown to influence milk yield of grazing dairy cows (Gowen et al., 2003) and differences in ploidy also impact on pasture production, sward nutritive value and animal performance (Balocchi and López, 2010; Wims et al., 2013). The use of tetraploid cultivars has slowly increased in the last few decades but diploid cultivars still predominate the market in Ireland and other temperate regions such as New Zealand and Chile (Balocchi and Lopez, 2010). For instance, sales of tetraploid cultivars in Northern Ireland increased from 5% to 30% from 1980 to 2004 (Gilliland et al., 2007).

2.4.4 Perennial ryegrass evaluation indices

In Ireland the Pasture Profit Index (PPI; Figure 2.10; McEvoy et al., 2011; O’Donovan et al., 2017) was developed to identify the economic merit of PRG cultivars for pasture-based ruminant production systems. It has enabled farmers and companies to select cultivars for traits they deem important. The PPI uses a combination of traits to give an overall euro value per ha for each cultivar, with some traits being given greater value in the index than others. Sub-indices within the PPI are based on spring, summer and autumn pasture growth, sward quality, silage produced per year and sward persistence. Spring and autumn growth receive a higher euro value because extra pasture grown at these times of the year is worth more to farmers as it replaces more costly feed such as silage or concentrate. Grass cultivars with a higher digestibility are also given a higher euro value, as are cultivars that have a higher persistency in the sward. The PPI therefore guides farmers in choosing the grass seed mixtures that will provide the highest financial benefits. As the sub-indexes are also published for each trait, farmers can select the best cultivars for a particular trait, if that is of particular importance to their grazing system.

Similarly in New Zealand, Dairy NZ have created the Forage Value Index (FVI) which they describe as an independent, region specific, profit-based index for short-term and PRG cultivars (Chapman et al., 2017b). The FVI for PRG cultivars is calculated based on the seasonal DM yield traits using cultivar-specific performance values as well as trait information on seasonal metabolisable energy (ME) content and persistence traits. The FVI is
relatively new and new traits will be included over time and with performance also being validated under grazing scenarios (Ludemann et al., 2017; Ludemann et al., 2018).

Figure 2.10 National recommended perennial ryegrass list with Pasture Profit Index 2019

2.4.5 Effect of ploidy on pasture production and sward nutritive value

There are conflicting reports on the DM production differences between tetraploid and diploid PRG cultivars. Balocchi and Lopez (2010) found diploid cultivars to have higher DM yields compared to tetraploids, however other research has found the opposite with tetraploid cultivars out yielding diploids (Connolly, 2001; Burns et al., 2013). Ploidy has also been shown to effect sward nutritive value. As previously mentioned, the increased proportion of cellular content in tetraploid cultivars increases the concentration of soluble carbohydrates, proteins and lipids, and improves forage digestibility (Wilkins, 1991; Smith et al., 2001; Gilliland et al., 2002; Nair, 2004). Regardless of ploidy, as PRG matures the proportion of stem and dead material increases with a mirror decline in leaf proportion, which ultimately lowers organic matter digestibility (OMD) content (Curran et al., 2010). Balocchi and Lopez (2010) showed that tetraploid cultivars consistently had higher digestibility than diploid
cultivars. Burns et al. (2013) completed an in-depth plot study over five years which showed tetraploid swards to have significantly greater DM digestibility values and higher water soluble carbohydrates (WSC) concentrations, but lower crude protein and DM concentrations than diploids.

2.4.6 Effect of ploidy on milk production

Milk yield advantages for cows grazing tetraploid cultivars compared to diploid cultivars have been reported previously (Castle and Watson, 1971; Lantinga and Groot, 1996; Wims et al., 2013). Wims et al. (2013) compared the milk and MS yield of cows grazing two diploid and two tetraploid cultivars and concluded that one of the tetraploid cultivars had significantly higher milk ($P < 0.001; + 0.9$ kg/day) and MS ($P < 0.01; + 0.08$ kg/day) yield compared to the three other cultivars. This difference was attributed to a more favourable sward structure and nutritive value. However, the milk yield from cows grazing the other tetraploid cultivar was similar to the two diploid cultivars. This indicates that the variance between cultivars may be higher than between ploidy. Therefore, identifying cultivar characteristics that can influence animal performance could greatly benefit plant breeders and subsequently pasture-based systems. Similarly, Lantinga and Groot (1996) reported a milk yield advantage with tetraploids relative to diploids over a short experimental period. Additionally, in a grazing preference study O’Riordan (1997) found that tetraploids predominated among the highest ranked cultivars for grazing preference over diploids.

2.4.7 Effect of ploidy on dry-matter intake

The DMI of forages varies significantly between plants and plant growth stages. Dry-matter intake has been linked to the neutral detergent fibre (NDF) content of forages; with low NDF content forages (red clover (*Trifolium pratense* L.), white clover, alfalfa (*Medicago sativa* L.), leafy PRG etc.) associated with higher animal DMI compared to high NDF content forages (seeded PRG, timothy (*Phelum pratense* L.) etc.; Mertens, 1987; Oba and Allen, 1999). Certain forages are also more palatable to animals and therefore can influence DMI. Balocchi and Lopez (2010) showed that cows grazing diploid and tetraploid swards had a preference to graze tetraploid cultivars, illustrated by a higher utilisation rate and lower post-grazing residual. This may infer a relationship between grazing preference and DMI, with
animals voluntarily grazing for longer and lower into the sward. Gowen et al. (2003) found higher DMI from late heading compared to early heading PRG cultivars when cows were stocked to allow adequate feed allocation. The higher performance with the late heading PRG cultivars was associated with a higher proportion of green leaf in the grazed horizon. Tas et al. (2005) found no differences in DMI when comparing eight diploid PRG cultivars differing in WSC content and inconsistent differences in crude protein and NDF content between the cultivars.

2.5 White Clover

2.5.1 Use of white clover

Clover is the most important forage legume in temperate regions of the world (Andrews et al., 2007; Lüscher et al., 2014) because of its suitability to a wide range of climatic conditions, high nutritional value and digestibility (Søegaard, 1993). Clovers also have the ability to biologically fix atmospheric N (Ledgard and Steele, 1992). Typically red clover is used in short-term leys and in silage cutting systems as red clover does not have long term persistence and only tolerates low artificial N inputs when sown with grasses (Boller and Nösberger, 1987; Clavin et al., 2017). White clover is mainly used in grazing systems as it can compete with grass and establish quickly (Chapman et al., 2017a). The use of white clover in grazing systems has been commonplace, particularly in countries like Ireland and New Zealand, and it has well established benefits such as biological N fixation (BNF), enhanced sward nutritive value, complementary seasonal growth patterns compared to commonly used grass species, and improved herbage intake and utilisation (Chapman et al., 1996). However, as the use of artificial N has increased, white clover use has declined in temperate grazing systems, as it can struggle to compete with high yielding grasses and persist in high N systems (Harris and Clark, 1996; Glassey et al., 2013).

2.5.2 Morphology and growth

White clover establishment is initially supported by the seed reserves in the seedling phase (Figure 2.11) following germination. During its relatively long establishment phase, white clover has two distinct morphological growth forms, a tap root stage (which can last up to two years; Figure 2.12) followed by a clonal growth stage (Figure 2.13). Death of the tap root
and primary stolon initiates a process of fragmentation of the tap root plant into a number of independent clonal plants which comprise the initial population of the clonal growth stage (Brock et al., 2000). During the seedling phase white clover seeds germinate faster than PRG, however the subsequent development of white clover is slow (Brock and Hay, 2001). White clover growth follows a typical seasonal trend with growth rates highest in late spring and summer and lowest in winter. White clover germinates at 8°C + which is slightly higher than PRG at 4-6°C, resulting in lower white clover plant populations in early spring sowings, due to reduced competition with PRG (Davies and Evans, 1982). The minimum soil temperature required for white clover to grow is 5°C with optimum temperature being approximately 24°C (Frame and Newbould, 1986; Hart, 1987; Brock et al., 1989). White clover is not tolerant of continuous cold conditions and survival at -10°C is low with leaf senescence occurring over winter after periods of frosts (Frame and Newbould, 1986). White clover flowers typically appear from May onwards in Ireland and are usually pollinated by bees and other insects.

Figure 2.11 Seedling phase of white clover
Figure 2.12 Tap root phase of white clover

Figure 2.13 Clonal growth phase of white clover
2.5.3 Management of white clover

One of the main challenges of white clover swards is trying to establish and maintain a balance between white clover and its companion species (Chapman et al., 1996). White clover has a small seed with low energy reserves, poor cool season activity and requires shallow sowing (2-3 mm; Brock and Hay, 2001). Establishment, emergence rate and growth of white clover is poorer in clay soils where the soil is hard and compacted. However, growth rates tend to be better from white clover when the soil has been preceded by a tillage crop (Brock and Kane, 2003). As PRG has a faster leaf appearance rate than white clover, grazing management in the seedling phase is very important, to reduce the competition between PRG and white clover (Brock and Kane, 2003; Brock and Hay, 2001). Regardless of the livestock grazing system employed, frequent defoliation during spring will favour white clover growth and promote a higher contribution through the following grazing seasons. Brock and Kane (2003) showed spring grazing management had clear effects on plant growth as rotational grazing with cattle resulted in larger plants, while set stocking with sheep from early spring reduced plant development and plant growth rates, which never fully recovered. With dairy cows, frequent grazing in summer is optimum, while for sheep, less frequent defoliation in summer is recommended as they can selectively remove more white clover foliage to low levels. Overgrazing by cattle in summer is also detrimental to white clover, possibly due to excessive loss of stolons. White clover persistence is dependent on stolon development and replacement. During winter, more than 90% of stolons can be buried, by treading and earthworm activity, with new stolons establishing on the soil surface during spring and summer. However, during spring white clover plant populations are fragile and susceptible to mismanagement and environmental stresses (Caradus et al., 1996). Increasing the interval between defoliations allows the development of larger plant organs, but has no effect on the structure of plants in terms of number of leaves, stolons, roots and branching complexity (Brock et al. 1988). Soil fertility also has a major impact on white clover establishment and persistence. In a new pasture with high soil fertility and where fertiliser N is used, white clover can struggle to compete and develop unless the grass can be kept in control through effective grazing management (Harris and Clark, 1996). By contrast, lowering soil fertility (as with tillage and not applying fertiliser N) will favour white clover because of its N fixing ability, without affecting PRG establishment. Although the PRG will not grow as well, it will survive to respond at a later stage as soil fertility builds through N fixation or N fertiliser application (Caradus et al., 1996). The supply of potassium (K) and phosphorous (P) in the
soil can limit white clover growth with P being particularly important for shoot and leaf development at establishment. However, K deficiency will limit shoot development long term which would majorly affect persistence (Bailey and Laidlaw, 1998).

2.5.4 White clover varieties

White clover is classified by leaf size: small, medium or large. Small leaf size cultivars are better suited to continuous grazing and are more tolerant of close defoliation (suited to sheep grazing), medium leaf sized cultivars are most suited to rotational grazing, and large-leaved varieties are more suitable for low stocking rates conditions or cutting systems as they are less tolerant of close defoliation and typically have higher DM yields (Andrews et al., 2007). Similar to PRG, the Irish Department of Agriculture has a recommended list for white clover varieties (Figure 2.14). They provide data on white clover yield and content in a PRG sward and sub-divides the cultivars into their leaf size class (small, medium and large). The use of white clover in Northern Ireland was relatively stable from 1980 to 2004 with white clover seed sales accounting for 4% of seed sales in 1980 to 3% in 2004 (Gilliland et al., 2007). A similar use pattern is assumed across the remainder of the island. These stable sales markets for white clover seed could be linked to the common practice of including a small amount of white clover seed in pre-made seed mixtures. This is common practice in the Republic of Ireland and Northern Ireland with a typical pre-made seed mixture including 1.2 to 2.5 kg white clover seed in a standard 30 kg/ha mixture. Currently the majority of seed mixtures for sale in Ireland comprise mainly of 60-70% of diploid PRG cultivars mixed with 30-40% tetraploid cultivars with frequently a small amount of white clover (0-5%) included. The Irish governments Climate Action Plan published in 2019 specifies the increased role that white clover should play in reducing N fertiliser use on farms by including white clover in all grass seed mixtures in the future (Department of Communications, Climate Action and Environment, 2019).
2.5.5 Pasture production and nutritive value

The inclusion of white clover in PRG swards has previously been shown to increase pasture DM production compared to PRG-only swards (Frame and Newbould, 1986; Ledgard and Steele, 1992; Enriquez-Hidalgo et al., 2015; Rodriguez, 2016). Typically, studies compare high N fertilised PRG-only swards to low N fertilised white clover swards. Therefore, similar or lower pasture DM production for PRG-white clover swards compared to PRG-only swards has also been reported. Egan et al., (2018) found similar pasture production between PRG-only swards and PRG-white clover swards receiving 250 kg N per annum and also PRG-white clover swards receiving 150 kg N. In contrast, Humphreys et al. (2009) recorded lower annual herbage DM production on white clover swards receiving 90 kg N/ha, compared to PRG swards receiving 226 kg N/ha. The low growth rates of white clover during spring can
compromise the overall annual pasture DM production of PRG–white clover swards (Frame and Newbould, 1984), although N fertiliser application can overcome this if strategically applied in the period from spring to early summer (Whitehead, 1995).

White clover has been shown to improve herbage nutritive value in numerous studies (Beever et al., 1985; Laidlaw and Teuber, 2001; Dewhurst et al., 2009). Perennial ryegrass–white clover swards have been reported to have a higher OMD content compared to PRG-only swards (0.77 vs. 0.80 g/kg DM; Enriquez-Hidalgo et al., 2018), increased crude protein content of up to 4% (Dewhurst et al., 2009; Rodriguez, 2016) and lower NDF content (Egan et al., 2018). The nutritive value of PRG swards declines mid-season, typically from early June onwards when PRG starts heading (Beecher et al., 2015). White clover growth rate increases from early summer onwards, and white clover can then contribute a large proportion of the sward herbage mass and nutritive value (Frame and Newbould, 1986; Ledgard and Steele, 1992). Thus, in PRG–white clover swards, the value of white clover is arguably greatest in the latter part of the grazing season, when the seasonal growth and nutritive value patterns of the two species complement each other.

2.5.6 Biological nitrogen fixation

White clover can contribute on average 185 kg N/ha per annum especially in low N fertiliser application swards (Ledgard and Steele, 1992, Harris et al., 1997). White clover roots have the ability to form nodules that contain symbiotic N-fixing bacteria. The N-fixing bacteria are usually present in the soil and multiply at points on the rhizosphere of the white clover roots (Crush, 1974). This symbiotic relationship involves white clover supplying the bacteria with carbon in return for the biologically fixed N. Carbon supply can therefore be limited by clover, and in high N fertilised soils clover will stop supplying carbon. The minimum temperature for BNF is 9°C with a wide range between 13-26°C and a maximum temperature of 30°C before the enzyme required for BNF is inhibited (Frame and Newbould, 1986; Hart, 1987). White clover can play a role in the sustainable development of pasture-based milk systems by reducing the quantity of N fertiliser required and therefore the cost of N fertiliser, and increasing pasture DM production in late summer and early autumn (Ribeiro Filho et al., 2003; Humphreys et al., 2009; Enriquez-Hidalgo et al., 2018). A key challenge of mixed swards is to improve the reliability of white clover to increase annual inputs from BNF and
effectively integrate the strategic use of fertiliser N without losing the benefits from white clover (Caradus et al., 1996).

2.5.7 Environmental impact

As mentioned previously BNF has a positive impact in grazing systems, allowing a reduction in the use and cost of artificial N fertiliser. However, this is often wrongly associated with a perceived environmental benefit where low or no N fertilised white clover swards are viewed as better for water quality than N-fertilised PRG-only swards. This is a simplistic view of a complex matter where overall N inputs and N outputs should be considered and not just the source of N. With regards to nitrate leaching in soil water, it must be acknowledged that biologically fixed N can leach as readily as artificial N (Ledgard et al., 2009; Chapman et al., 2018). It is well recognised that applying N fertiliser when mineral N contents of the soil are relatively high, is a recipe for financial as well as environmental loss (Chapman et al., 1996).

In grazing systems this means avoiding N inputs during dry periods or in late season as the potential for growth falls relative to the potential for N loss by leaching and run-off (Chapman et al., 1996). In 100% white clover swards, nitrate leaching was shown to be > 60 mg N/l in soil water, however in mixed swards with < 20% white clover content, soil water was maintained at low N concentrations (Macduff et al., 1990). Chapman et al. (2018) concluded in a review that there was no evidence to suggest that leaching differs when N is supplied solely by BNF in mixtures, by BNF plus chemical fertiliser in mixtures, or solely as chemical fertiliser to PRG-only swards. The risk of volatilisation of N from urine patches is also a concern in grazing animals, which is increased in white clover swards due to the higher partitioning of N eaten into urine excreted (due to a lower ratio of soluble sugar and starch to N in herbage) and therefore higher concentrated urine patches (Chapman et al., 2018). However, N-use efficiency should also be considered as animals grazing white clover swards have been shown to have higher outputs in growth rates or milk production along with higher pasture production and nutritive value. There is evidence that N-use efficiency in white clover swards is higher than fertilised PRG swards (Ledgard et al., 1999; Nyfeler et al., 2011). This implies that nitrous oxide emissions in white clover swards may be lower since N-use efficiency is negatively related to nitrous oxide emissions (Olesen et al., 2006; Schils et al., 2008). This is supported by Li et al. (2011) who observed a clear reduction of nitrous oxide emissions when N fertiliser is replaced by BNF.
2.5.8 Milk production from white clover

Due to the numerous benefits of white clover previously mentioned such as higher nutritive value, higher voluntary DMI and faster rumen passage rate, it can be expected that cows grazing PRG-white clover swards will see a milk production benefit. However, the correct sward white clover content is required to have an effect on the animal response in mixed swards. Andrews et al. (2007) indicated that in mixed swards a white clover content of at least 20% would be required to have an effect on milk production. Harris et al. (1997) reported increased milk yields from cows fed swards where there was 50% and 80% white clover. Milk yields of cows fed 50% and 80% white clover diets ad libitum or restricted were not significantly different but were significantly higher than for cows fed 20% white clover. The increase in milk yield was credited to increased DMI associated with high clover diets, and also the higher nutritive value of white clover. Results showed the optimum white clover content in the diet for milk production was 55-65% and there was little benefit in a sward clover content of above 60% as there is little animal production response above this (Harris et al., 1997). Dineen et al. (2018) completed a meta-analysis on white clover inclusion in PRG swards and its impact on milk production, and found with a white clover content of 31.6%, mean daily milk and milk solids yield per cow were increased by 1.4 and 0.12 kg, respectively. Similarly, Egan et al. (2018) found an increase in cumulative MS per cow of +34 kg from white clover swards compared to PRG-only, however the average white clover content of the sward was approximately 25% throughout the grazing season. Ribeiro Filho et al. (2003) also recorded significantly higher daily milk and MS yield from cows grazing white clover swards compared to PRG-only, with a white clover content of approximately 40%. Ribeiro Filho at al. (2003) associated the increase in milk production to an increase in the herbage DM, energy and protein intake, and not with an improvement in the nutritive value of the herbage.

2.5.9 Dry-matter intake from white clover

One of the main benefits of white clover for grazing ruminants is the higher DMI and higher digestion rate (Dewhurst et al., 2009). Additionally a partial preference for white clover when grazing PRG-white clover swards has been recorded (Rutter et al., 2004; Rutter, 2006). Animal preference for grazing white clover over PRG has been well established with Rutter
et al. (2004) showing cows chose a 74% white clover diet over PRG when offered both. This preference has been linked to a faster rumen passage rate of white clover compared to PRG due to its lower NDF and ADF content. The post-grazing heights of swards can also illustrate animal preference, with cows grazing lower into the swards of more palatable forages. As mentioned previously, the resistance of the feed to breakdown during chewing, ruminating and in the rumen also affects voluntary DMI of forages (Minson, 1990). White clover particles have been shown to break down faster than PRG in sheep (Moseley and Jones, 1984) which indicates that clover has a lower resistance to chewing than PRG due to lower cell wall contents and lower length/width ratio of fibre (Minson, 1990). The faster rate of particle size reduction of white clover compared to PRG (Moseley and Jones 1984; Thomson et al. 1985; Minson 1990) can result in a lower rumen retention time and consequently can affect DMI levels. Rogers et al. (1982) showed that cows consuming white clover pasture produced more milk and gained more live-weight (85 vs. 80 kg) due to a 30% higher DMI. It can therefore be concluded that the higher passage rate combined with lower rumen retention rate and higher forage nutritive value of white clover swards increases DMI (Harris et al., 1997). Ribeiro Filho et al. (2003) found cows grazing swards with 40% white clover resulted in a significant increase in DMI and milk yield. Similarly, Egan et al. (2018) found cows grazing white clover swards in May and July had greater DMI compared to PRG-only swards, which also impacted milk yields.

2.5.10 Bloat

One issue which can arise when grazing white clover swards is the issue of ‘pasture bloat’. Bloat can occur on PRG pastures but is much more common in swards with high clover content (Clarke and Reid, 1974). Bloat is caused by the production and retention of gas in the rumen of cattle. The problem arises when the production of gas is higher than the release through ‘belching’, this imbalance of gas production and removal leads to bloat from excessive foaming of the contents of the rumen (Clarke and Reid, 1974). This persistent foam in the rumen of cattle has been linked to the absence of condensed tannins in plant material (Jones et al., 1970). Previously white clover cultivars have been tested for the presence of tannins (specifically flavanols) and although the leaves lacked tannins, petioles had trace amounts and all white clover flowers contained tannins (Jones et al., 1973). Therefore, the risk of bloat in white clover swards is much lower when the plant is flowering from mid-May
onwards. This has previously been supported with decreased probability of bloat found with advancing stages of plant maturity (Majak et al., 1995). Condensed tannins also have the added benefit of protecting plant proteins from microbial degradation in the rumen, which results in increased amino acid flow to the intestines which can benefit animal health and productivity (Woodfield and Clark, 2009). Condensed tannins also have been shown to increase N-utilisation in the digestive tract and protect against some parasites (Rochon et al., 2004).

2.6 Cow Genotype

2.6.1 Dairy cow breeding strategies in Ireland

The ideal cow for pasture-based systems has the ability to produce a large quantity of high value milk, has good reproductive performance, good health status, longevity, high feed efficiency, is easy care, and has a low environmental footprint (Berry, 2015). In the context of seasonal pasture-based systems, there is increased importance on good reproduction performance due to the significant costs associated with reproductive inefficiency in dairy herds (Shalloo et al., 2014). The primary dairy cow breed in Ireland is Holstein-Friesian (HF), comprising 90% of Irish dairy herds (DAFM, 2018). North American Holstein genetics became popular in Ireland and in other European countries in the 1980’s with an increase in sires used from 10% in 1977 to 80% in 1998 (Simm, 1998) due to breeding strategies based solely on increasing milk yield per cow. However, it soon became clear there was an antagonistic relationship between milk yield and reproductive traits, with an unfavourable genetic correlation between milk yield and days open of approximately 0.35 (Windig et al., 2006). Pryce et al. (1998) estimated an increase in calving interval of five to ten days per 1000 kg of milk yield when selection was based on milk production traits only. As a result, reproductive performance in Ireland declined significantly from the 1980’s up to the 2000’s (Mee, 2004). For example surveys undertaken in the 1960’s and 1970’s reported pregnancy rates to first service of over 60%, whereas a later survey in 1999 reported a pregnancy rate to first service of 48% (Evans et al., 2006). The introduction of the Economic Breeding Index (EBI; Berry et al., 2004; Berry et al., 2005) has led to improvements in Ireland’s national herd reproductive performance while also increasing milk yield and composition (CSO, 2019; ICBF, 2019b). The EBI is reflective of a modern selection index whereby milk production traits typically comprise approximately 50% of the total index (Cole and VanRaden, 2018).
and includes functional traits specifically selected to improve reproductive performance (Miglior et al., 2017; Cole and VanRaden, 2018; Pryce et al., 2018). This change in dairy selection indices has generally halted and in some cases (e.g. Ireland) reversed the decline in reproductive performance as well as other important functional traits in dairy cattle (Carvalho et al., 2018; Cole and VanRaden, 2018; Lucy, 2019) although not all countries have seen improved reproductive performance (Pryce et al., 2014).

2.6.2 Economic Breeding Index

As discussed previously the EBI was introduced in Ireland in 2001 and is a single figure profit index aimed at helping farmers identify the most profitable bulls and cows for breeding dairy herd replacements (Berry et al., 2004; Berry et al., 2005). It now includes seven sub-indexes related to profitable milk production; (1) Milk production, (2) Fertility, (3) Calving performance, (4) Beef Carcass, (5) Cow Maintenance, (6) Cow Management and (7) Health. Figure 2.15 shows the relative emphasis for each of the seven traits from the introduction of the EBI up until 2018. Initially only two traits were included; milk production and fertility. However, calving and beef traits were introduced in 2005, closely followed by health traits in 2006, maintenance in 2010 and finally management in 2013. Figure 2.16 shows the actual percentage emphasis along with what exact traits feed into each sub-index. The economic values in each sub-index are based on data collected from Irish dairy farms and the dairy industry such as calving surveys, milk recording, weights and birth and death dates which are sent to the Irish Cattle Breeding Federation from farmers, milk recorders, marts, factories etc. Figure 2.17 shows the improvements in the national six-week calving rate and calving interval from 2008 to 2018 since the introduction of the EBI (ICBF, 2019a). However, nationally only 64% of the dairy herd calves in the first six-weeks of the calving season and calving interval is 387 days, both of which are below target. The aim is to have 90% of the herd calved in the first six weeks and to have a calving interval of 365 days. Milk and MS yield per cow have also increased concurrently with the improvement in reproductive performance as can be seen in Figure 2.18. For example, MS yield per cow has increased from 366 kg/cow in 2013 to 407 kg/cow in 2016 in milk recorded herds (ICBF, 2019b).
Figure 2.15 The development of the relative emphasis of EBI traits from introduction until 2018. Source: ICBF

**Figure 2.16** Economic values and percentage emphasis of the traits in the EBI calculation
**Figure 2.17** Trends in the national six-week calving rate (\%; blue) and calving interval (days; green) from 2008 to 2018 (Source ICBF, 2019a)

**Figure 2.18** Daily milk solids yield (kg fat + protein) from 2013 vs. 2017 (Source ICBF, 2019b)
2.6.3 Reproductive performance

Reproductive performance is a critical part of any dairy production system as it is said to be the largest component of the productive life of the cow (Lucy, 2001). This can be explained as the milk production from a cow is solely dependent on her ability to become pregnant as the lactation cycle can only be initiated and renewed by pregnancy (Lucy, 2001). Pregnancy occurs through a series of individual events in sequence. After calving the following process occurs; the uterus involutes, oestrous cycles resume, oestrus is expressed and detected, sperm are deposited in the reproductive tract and capacitate, ovulation occurs and is followed by fertilisation and the corpus luteum forms and produces sufficient progesterone to maintain pregnancy (Lucy, 2019). Improving an animal’s reproductive performance is of particular importance as it makes them more suitable and profitable for spring-calving pasture-based systems, due to lower replacement costs, higher survivability, increased milk and MS yield due to a greater proportion of mature cows in the herd (Delaby et al., 2018). This is because milk yield is 16-19% greater from 2nd lactation cows and 28-31% greater from 3rd lactation cows compared with 1st lactation cows (Horan et al., 2005a). Therefore, having a higher proportion of mature cows in the herd will positively impact milk production while also reducing the costs associated with rearing replacement stock. There are also other higher costs associated with reproductive inefficiency including increased culling costs, sub-optimal calving date, higher labour costs, and increased artificial insemination (AI) and intervention costs (Shalloo et al., 2014). Key reproductive traits affecting overall profitability include; calving interval, longevity, use of AI, level of management, labour efficiency and overall pregnancy rate however, six-week pregnancy rate is the most important reproductive key performance indicator in pasture-based production systems (Shalloo et al., 2014). A 1% change in cows achieving the six-week pregnancy rate is associated with a change in profit of €9.26/cow per year and €3.51/heifer per year (Shalloo et al., 2014).

2.6.4 Crossbreeding and heterosis

Crossbreeding is a common tool used within the agricultural industry with crops and animals such as pigs, beef cattle, sheep and poultry. However, it has had limited use in the dairy industry worldwide where cows have been traditionally selected based on body conformation and production (Hansen, 2006). The main aim of crossbreeding is to exploit favourable
characteristics of ‘alternative’ genotypes, remove the negative effects associated with inbreeding and capitalise on heterosis (Buckley et al., 2014). Heterosis is maximised when there is greater genetic distance between the parental breeds (VanRaden and Sanders, 2003), but it should be noted that heterosis can and does occur within breeds. Heterosis can also be described as the consequence of outbreeding. Outbreeding involves the mating of individuals less related than the average pair of individuals in a population, therefore crossbreeding is one form of outbreeding (Hansen, 2006). Heterosis, therefore, is not just limited to crossbreds, as it exists when animals with different homozygotes of additive genes (i.e., one parent has two copies of the A variant and the second parent has two copies of the B variant) mate, producing an offspring with one copy of each gene (AB, heterozygous). Nonetheless the larger responses are experienced when parental cattle of different breeds are crossed, such as crossbreeding NZ Holstein-Friesians with North American Holsteins as they do not have a recent common ancestry.

The actual heterosis value in a population and/or for a given trait can be either expressed as a percentage of the mean (e.g., 5%) or in the units of measurement (e.g., 50 kg milk solids or 3 days calving interval). In simple terms, the actual heterosis (as a percentage) observed in a group of outbred individuals may be defined as:

\[
\text{Heterosis} = \frac{(\text{Mean outbred performance}) - (\text{Mean of purebred performance})}{(\text{Mean purebred performance})} \times 100
\]

Source: Berry, 2018. Positive Farmers Conference

Figure 2.19 shows the expected heterosis coefficient for each generation when a two-way rotational cross system is implemented. However, it has been hypothesised that a three-way rotational breeding system would maximise heterosis benefits even more while also possibly adding additional traits and being more profitable in a pasture-based system (Lopez-Villalobos et al., 2000). When implementing a crossbreeding strategy on a farm, there are three main future breeding options; backcrossing using one of the parent breeds, use of a crossbredsire, or introducing a third genotype into a 3-way rotational crossing system (Lopez-Villalobos et al., 2000). However, there have been very few studies examining three-way crossing as an option within pasture-based production systems.
2.6.5 Effect of crossbreeding on animal performance

There has been increased interest in crossbreeding for its reported benefits in terms of animal health and efficiency (Buckley et al., 2014). The Jersey breed is popular for crossbreeding with traditional HF cows particularly in pasture-based systems due to their smaller body size and ability to improve milk composition. There is also evidence to show improved health, fertility and longevity of Jersey crossbred cows compared with HF counterparts (Harris et al., 2001; Auldist et al., 2007). Crossbreeding of dairy cows has become popular in New Zealand, where pasture-based systems also dominate, with 48% of the national dairy herd now classified as crossbred (Dairy NZ, 2017). This is a large contrast to Ireland where approximately 5% of herds are considered crossbred (Coffey et al., 2016). In Ireland in 2017 52.1% of the sire selections for dairy dams were from HF bulls, with Jersey bulls accounting for only 2.1% (DAFM, 2017). Crossbreeding HF with Jersey has the advantage of producing an intermediate sized animal which produces milk of a higher fat and protein content (Heins et al., 2008a; Heins et al., 2008b). The higher protein and fat content of milk is advantageous with Ireland’s milk payment system which rewards milk fat and protein concentration but

Figure 2.19 Mean heterosis expected for each generation of a two-way rotational cross starting from purebreds in generation 0. Source: Berry, 2018.
penalises for milk volume (A + B - C i.e. fat kg + protein kg - volume). In recent studies, milk yield was greatest for HF cows, while MS yield was similar (Auldist et al., 2007; Prendiville et al., 2009) or greater for HF x Jersey cross (JEX) cows (Prendiville et al., 2011a; Coffey et al., 2016). Coffey et al. (2016) showed that the additional performance corresponded to a 5.6% increase for milk yield and 6.4% increase for MS yield per lactation for crossbred cows relative to the purebred parental average. Crossbreeding HF with Jersey has also resulted in improved reproductive performance in numerous studies. Prendiville et al. (2011a) found JEX cows to have a higher pregnancy rate to first service (+22%), six-week pregnancy rate (+19%) and 13-week pregnancy rate (+8%) compared to traditional HF cows. Other studies have also reported higher pregnancy rates to first service in JEX cows compared to HF cows (Heins et al., 2008b; Vance et al., 2013).

Other breeds commonly used for crossbreeding include Montbéliarde, Normande and Norwegian Red. When these breeds have been crossed with HF their progeny have shown superior reproductive performance with similar or increased MS production per cow when compared with HF (Heins et al., 2006; Walsh et al., 2007; Begley et al., 2009). Theoretical advantages of a three-breed rotational crossing system have previously been discussed with Lopez-Villalobos et al. (2000) hypothesising that a 3-way rotational crossing system could increase profitability for pasture-based systems in New Zealand. A recent study compared a 3-way cross of Swedish-Red x Jersey/Holstein with pure Holstein cows and found similar MS production and improved functional traits (lower mastitis and ovarian dysfunction incidences; Ferris et al., 2018). Shonka-Martin et al. (2018) also compared a 3-way cross of Montbéliarde, Viking Red, and Holstein to purebred Holstein cows for body traits and milk production and found that MS production of the 3-way breed did not differ from Holstein cows from 4-150 days in milk in their first three lactations and an improved BCS was observed with the 3-way cross.

2.6.6 Effect of crossbreeding on dry-matter intake and feed conversion efficiency

In pasture-based systems dairy cows must be capable of achieving large intakes of grazed pasture to meet energetic requirements in order to produce high MS yield per cow (Buckley et al. 2005). Differences in DMI between genotypes have been recorded previously with Coffey et al. (2017) observing significantly lower grass DMI from F1 Jersey x HF cows.
compared to HF. These differences were consistent throughout lactation and at three differing stocking rates. Similarly, Prendiville et al. (2009) compared DMI between HF, Jersey and Jersey x HF cows and found HF cows to have the highest DMI, followed by Jersey x HF and Jersey ($P < 0.001$).

Differences in feed conversion efficiency (FCE) have also been observed between breeds, in terms of MS produced per total DMI, with purebred Jersey cows (0.088 kg) being the most efficient, followed by JEX (0.087 kg) and lastly HF (0.079 kg; Prendiville et al., 2009). The higher FCE with purebred Jersey cows has been attributed mainly to their lower body weight (BW) combined with their larger gastro-intestinal tract capacity relative to their body size (Smith and Baldwin, 1974; Beecher et al., 2014). Similarly it has been reported that German black-and-white cows had only 80% of the digestive capacity of purebred Jersey cows when measured as rumen/reticulum volume relative to BW (Nagel and Piatkowski, 1988). The Jersey cows weighed 200 kg less than the German black-and-white cows, but their rumen/reticulum volume was only 20 litres less. This suggests that Jersey cows have a large capacity to consume roughage per unit BW compared with other cow breeds (Nagel and Piatkowski, 1988).

Interestingly, Prendiville et al. (2009) and Vance et al. (2012) found when herbage allowance was similar for all cows, no difference was observed in DMI/cow per day for HF and JEX cows, despite HF cows weighing approximately 50 kg more than JEX cows. However, it should be noted that energy requirements are lower for JEX cows compared to HF which allows them to be stocked higher on farms (Beever and Doyle, 2007; Coffey et al., 2017). A negative association between cow BW and FCE has also been reported, with FCE increasing as BW decreased, adding support to the findings that lighter animals consume more feed and produce more milk per 100 kg BW (Clark et al., 2007; Prendiville et al., 2009). Goddard and Grainger (2004) concluded their review on the effect of dairy breed on FCE by stating the enhanced intake capacity and ability to consume roughage of Jerseys could be an advantage in pasture-based systems as they are more forage-based and often have lower roughage quality than TMR diets. Feed Conversion Efficiency in the dairy industry is most commonly defined as the amount of MS produced per kg DMI (kg MS/kg DMI) and is regarded as an important determinant of farm productivity (Goddard and Grainger, 2004). Goddard and
Grainger (2004) stated that improvements in FCE could be achieved, when all other things are equal, if a cow:

1. Achieves a higher feed intake per unit BW
2. Has lower losses of energy in faeces, urine or methane, for a given DMI
3. Has a lower loss of energy as heat (mainly energy needed for maintenance), for a given DMI
4. Partitions more metabolisable energy to milk and less to body tissue. This will improve FCE in the short term, but in the long term continued weight loss is not sustainable

2.7 Economics of Grazing Systems

2.7.1 Profitability drivers in grazing systems

As previously stated, PRG is the main grass species grown in temperate regions of the world where it is the cheapest feed available for dairy cows (McGilloway, 2005; Finneran et al., 2012). In pasture-based systems grazed forage can make up to 80% of a cow’s diet. Therefore any increase in forage utilised or milk produced from forage can significantly impact farm profitability (Hanrahan et al., 2018). A previous economic simulation has shown that irrespective of milk price, increasing the level of reseeding in an Irish dairy system has a positive effect on profitability, due to additional pasture production and, when matched by an increased stocking rate, resulted in increased pasture utilisation (Shalloo et al., 2011). Pasture utilisation is one of the most important factors influencing profitability in pasture-based dairy production systems and Hanrahan et al. (2017) reported that for every 1 t DM/ha increase in pasture utilised, net profit per ha increased by €173. The importance of pasture utilisation for the profitability of pasture-based systems has been highlighted previously by studies in Ireland (Ramsbottom et al., 2015) and New Zealand (Macdonald et al., 2017).

The inclusion of purchased supplementary feeds to increase milk production per cow (through greater DMI) and per ha (through increased stocking rate) is often proposed as a strategy to increase profitability in pasture-based systems. Ramsbottom et al. (2015) reported that when supplementary feed use is increased in pasture-based systems, there is a decline in pasture harvested/ha. When the costs of producing unutilised pasture along with the
additional feed costs are accounted for, this results in lower profit. Ramsbottom et al. (2015) concluded that farmers considering intensification through the use of purchased supplements to increase stocking rate, must ensure that they focus on pasture management and total cost control to capture the potential benefits of supplementary feed use. Similarly, Macdonald et al. (2017) found operating profit declined as purchased feed increased, despite high marginal milk production responses. This has implications for the strategic direction of grazing dairy farms, particularly in export-oriented industries (such as Ireland and New Zealand), where the prices of milk and feed inputs are subject to the considerable volatility of international markets.

2.7.2 Effect of white clover on economic performance

The use of legumes in grazing swards has the potential to reduce the consumption of artificial N, reduce the carbon footprint of dairy systems and increase the nutritional quality of forage (Peyraud et al., 2010; O’Brien et al., 2014; Lüscher et al., 2014). With increasing N fertiliser costs in Ireland over the last 20 years due to growing demand worldwide and rising manufacturing costs, the cost of fertiliser driven sward production has increased. Andrews et al. (2007) reported that pasture production from white clover swards with no N input produced approximately 70% of the pasture produced from grass swards receiving 400 kg N/ha in a grass-based dairy production system. Likewise, similar studies in Scotland (Leach et al., 2000), Ireland (Ryan, 1986) and New Zealand (Ledgard et al., 1998), showed white clover swards receiving no input of fertiliser N could carry approximately 80% of the stocking density of PRG swards receiving up to 280 kg N/ha. Hence, there is interest in evaluating the potential of white clover to reduce artificial fertiliser N and contribute to the profitability of pasture-based systems of dairy production. However, the potential lower and more erratic pasture production and stocking rate of low N fertilised white clover swards may result in reduced profitability compared to high N fertilised PRG-only swards. Alternatively, the profitability of white clover swards receiving high levels of N should also be evaluated as they have the potential for higher pasture production and should support a similar stocking rate to conventional PRG-only swards. There has been limited economic analysis completed on production systems containing white clover swards compared to PRG-only swards. Humphreys et al. (2012) reported similar net margin/ha for PRG swards receiving high levels of artificial N compared to white clover swards receiving reduced N fertiliser annually.
Although the white clover swards had lower production costs (mainly due to reduced N fertiliser use), it also had reduced output due to a lower carrying capacity and stocking rate. Alternatively, Schills et al. (2000a) reported a higher gross margin per farm and per cow on low N-fertilised white clover swards compared to higher N-fertilised PRG swards.

2.7.3 Effect of cow genotype economic performance

As stated previously cow breed can have a significant impact on the profitability of pasture-based production systems due to differences in milk and MS yield, reproductive performance and health traits (McCarthy et al., 2007). The genetic improvement of dairy herds has been previously shown to increase farm profitability (Shalloo et al., 2004c; Evans et al., 2006; McCarthy et al., 2007). These studies showed similar milk yields from low and high genetic merit animals but large differences in reproductive performance, which ultimately resulted in lower lifetime milk yields, increased culling rates and higher replacement costs. Coleman et al. (2009) compared low genetic merit North American HF with high genetic merit North American and New Zealand HF cows. They found both high genetic merit groups had higher milk fat and protein content compared to the low genetic merit cows, which would achieve a higher milk price in the Irish milk payment system. Crossbreeding HF cows with Jersey is the most common form of crossbreeding in pasture-based systems in Ireland, New Zealand and Australia. The F1 crossbred cow typically has a lower milk yield compared to its HF counterpart, but has a higher fat and protein content which can result in similar or higher total MS yields (Auldist et al., 2007; Prendiville et al., 2011a; Vance et al., 2013; Coffey et al., 2016). Also the lower BW typically seen with crossbred cows coupled with their lower energy maintenance requirement means that they can be stocked higher than traditional HF cows (Coffey et al., 2017). Previous economic analyses undertaken have attributed higher profitability in crossbred herds due to higher revenue from milk receipts, greater lifetime milk production, improved reproductive performance and longevity and lower replacement rates relative to their purebred contemporaries (Lopez-Villalobos et al., 2000; Prendiville et al., 2011b).
2.7.4 Value of the cull cow and bull calf

One issue with crossbreeding, and crossbreeding HF with Jersey, is that the value of Jersey crossbred cull cows and male calves is lower, with Prendiville et al. (2011b) reporting a 12% reduction in the revenue received for cull cows (due to lower BW) and a 63% reduction in the value of JEX male calves compared with their HF contemporaries. Dairy calf-to-beef systems have been shown to be profitable in the past when compared to traditional suckler or fattening systems especially from pasture-based systems (Murphy et al., 2017). In Ireland, the predominant breed for dairy herds is HF, and bull calves are usually sold to be fattened for beef production or exported live. However, the use of Jersey bulls in breeding strategies has caused an issue with selling bull calves due to their smaller size and poor ability for meat production, which accumulates into a negative perception for beef finishing farmers (Nielsen and Thamsborg, 2002; Berry et al., 2018). In a beef finishing study, when JEX bull calves were compared with HF bull calves, carcass weight was reduced by 12% and a poorer carcass conformation was observed (McNamee et al., 2015). However, McNamee et al. (2015) also found Norwegian Red x HF bull calves to have similar beef production potential to HF bull calves, with superior carcass conformation at slaughter. In addition, dairy farming has been under public scrutiny recently with the welfare of the cow and calf being of most interest. Large retailers, conscious of the attitudes and opinions of their consumers are beginning to act to encourage their farmer suppliers to improve animal welfare with calf mortality and age at slaughter an area of concern (Mee, 2013).

2.8 Aims and Objectives

The research presented in this thesis was undertaken to expand the knowledge of the milk production effect of PRG ploidy and white clover inclusion from grazing swards, and to examine if an interaction exists between PRG ploidy and white clover. The effect of cow genotype is also explored within pasture-based systems in the context of milk production, reproductive performance and health traits to determine the suitability of each cow genotype for spring-calving pasture-based systems. A further objective is to investigate the DMI from each sward type and cow genotype along with calculating their production efficiencies to evaluate the productivity of each system. Finally an economic analysis is undertaken to determine the financial viability of each cow genotype grazing either PRG-only or PRG swards with white clover under varying scenarios.
### Chapter 3

**General Materials and Methods**

#### 3.1 Site description

The experiment was established in Teagasc Clonakilty Agricultural College, Co. Cork (Latitude: 51°63’N; Longitude: -08°85’E; 25-70 m above sea level) and ran for four years from 2014-2017. A dairy grazing platform of 43.6 ha was used with 75% of the experimental area reseeded in 2012 and 25% reseeded in 2013 by full cultivation (ploughing and tilling). The soil type was a free-draining, acid brown earth with a sandy loam to loam texture.

![Figure 3.1 Map of trial farm in Clonakilty and paddock layout](image)

#### 3.2 Experimental design

The experiment was a randomised block design with a 2 x 2 factorial arrangement of treatments. The four grazing treatments used for this study were; tetraploid-only PRG swards (TGO), diploid-only PRG swards (DGO), tetraploid PRG with white clover swards (TWC) and diploid PRG with white clover swards (DWC). The four tetraploid cultivars (Astonenergy, Dunluce, Kintyre and Twymax, sown at 37.5 kg/ha) and four diploid cultivars
(Aberchoice, Glenveagh, Tyrella and Drumbo, sown at 30 kg/ha) were sown as monocultures, with each cultivar sown ten times across the grazing platform. In the white clover paddocks a 50:50 mix of the medium-leaved white clover cultivars Chieftain and Crusader were sown at 5 kg/ha. This resulted in four farmlets being created with 20 paddocks per grazing treatment for the four years. Paddock’s for each treatment were balanced for location block, soil type and soil fertility throughout the farm. Each farmlet was 10.9 ha and stocked at 2.75 cows/ha. Three cow breeds were used for the experiment; Holstein Friesian (HF), Jersey x HF (JEX) and JEX x Norwegian Red (3WAY). The JEX cows were produced from HF cows mated with a Jersey sire to produce an F1 crossbred animal. The 3WAY cows were produced from F1 JEX cows mated with a Norwegian Red sire. Each year a minimum of 3 high EBI HF, Jersey and Norwegian Red sires were used. Every year ten cows of each genotype were assigned to one of the four grazing treatments and balanced for parity (1, 2 or 3+), calving date, BW, BCS and EBI, giving a single combined herd of 30 cows per grazing treatment and a total of 40 cows of each genotype on the experiment.

**Figure 3.2** Holstein Friesian cow used during the study
Power analysis was completed during the experimental design phase and was based on previously published experiments reporting variable differences for the same factors analysed in our study. The power analysis was used to calculate the sample size of cows required of each breed and for each grazing group to detect an effect with a given degree of confidence (95% in our case) for the variables reported. This was particularly important for variables which had a limited number of results such as cow pregnancy rate (only 1 recording per cow...
per year) as opposed to milk production (daily production for each cow for 285 days for 4 years).

Statistical significance is reported throughout this thesis as $P < 0.05$ and this indicates that the difference is unlikely to have occurred by chance. However, this does not mean that the difference is necessarily large, important, or significant in biological terms and may have occurred due to a large number of recorded results such as with milk protein % being recorded during each lactation week for each cow over 4 years.

### 3.3 Experimental management

#### 3.3.1 Grazing management

All treatments were grazed in a spring calving rotational system (Table 3.1). The main points of the plan are; get freshly calved cows out grazing as soon as possible post-calving, graze 30% of the farm area during February to stimulate regrowth for the second rotation, have 60% of the farm area grazed by March 17th, and to stretch the remaining 40% until early April (and later if growth rates are below normal). Cows were grazed day and night as they calved from February onwards as soon as weather conditions allowed. Typically, grazing began early-February and finished mid-November each year. Cows were supplemented with 4 kg concentrate post-calving and this was gradually reduced when cows were grazing full time, and when grass growth on the treatments met demand. Grazing management was achieved by weekly monitoring of average farm cover (AFC) for each treatment and using the online application ‘PastureBase’ to aid in decision making (Hanrahan et al., 2017). Daily feed allowance was typically 17kg of dry matter per cow per day. Target pre-grazing herbage mass (PrGHM) was calculated separately for each grazing treatment using the following formula:

$$\text{Target PrGHM} = (\text{stocking rate} \times \text{ideal rotation length} \times \text{daily herbage allowance per cow}) + \text{residual herbage mass}.$$
Table 3.1 Target rotation length (days), daily area allocated (ha) and proportion of total farm area grazed (%) for each week of spring.

<table>
<thead>
<tr>
<th>Week</th>
<th>Rotation (days)</th>
<th>Daily area (ha/day)</th>
<th>Total area grazed by week end (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>February 1-7th</td>
<td>100</td>
<td>0.4</td>
<td>7</td>
</tr>
<tr>
<td>February 8-14th</td>
<td>91</td>
<td>0.44</td>
<td>15</td>
</tr>
<tr>
<td>February 15-21st</td>
<td>82</td>
<td>0.49</td>
<td>23</td>
</tr>
<tr>
<td>February 22-28th</td>
<td>73</td>
<td>0.55</td>
<td>33</td>
</tr>
<tr>
<td>March 1-7th</td>
<td>64</td>
<td>0.62</td>
<td>44</td>
</tr>
<tr>
<td>March 8-14th</td>
<td>56</td>
<td>0.72</td>
<td>56</td>
</tr>
<tr>
<td>March 15-21st</td>
<td>47</td>
<td>0.86</td>
<td>71</td>
</tr>
<tr>
<td>March 22-28th</td>
<td>38</td>
<td>1.06</td>
<td>90</td>
</tr>
<tr>
<td>March 29th- April 4th</td>
<td>29</td>
<td>1.38</td>
<td>114</td>
</tr>
</tbody>
</table>
If a herbage deficit occurred across all treatments then concentrate supplementation was increased for all groups. However, if a herbage deficit occurred in less than all four treatments then silage produced from each treatment was used to supplement the deficit to each individual treatment group. During periods of inclement weather conditions (excessive rainfall), where grazing conditions were poor, on-off grazing was practised (Kennedy et al., 2009).

Residency time within paddocks was determined by targeting a post-grazing sward height (PoGSH) of 3.5-4 cm for the first and final grazing rotation and a target of 4-4.5 cm throughout the main grazing season. Cows within treatments were moved to their next paddocks when the target PoGSH was reached. No topping of paddocks took place over the four years and all excess forage was removed and conserved as silage. Inorganic N was applied equally across all four treatments in the form of Urea or Calcium ammonium nitrate at a rate of 250 kg N/ha per year. Inorganic phosphorus and potassium were applied at similar rates across all four treatments based on yearly soil test results.

### 3.3.2 Animal management

Each year approximately 20% of the cows on the experiment were replaced with primiparous cows to maintain the same parity structure for each grazing treatment and genotype. Four cows were removed during the experiment in 2014, three cows in 2015 and one cow in 2016 for various reasons (sickness, death etc.). When a cow was removed it was replaced by another cow of the same genotype and of similar BW to maintain the stocking rate in that treatment. Neither the cow that was removed nor the replacement cow’s data were used in the final analysis. Primiparous cows were given an 11 week dry period and multiparous cows a nine week dry period. The decision to dry off cows was based on BCS (cows with BCS < 2.75 were dried off earlier), level of milk production (i.e. cows producing < 8 kg/day of milk were dried off) and number of days from calving. Consequently, a total of 472 lactations from 242 spring calving dairy cows were used (35, 24, 24, and 24 primiparous and 81, 93, 95 and 96 pluriparous in 2014, 2015, 2016 and 2017, respectively). The EBI of each genotype is shown in Table 3.2. The EBI for each cow was calculated as the parental average EBI from the January 2019 Irish Cattle Breeding Federation (ICBF) evaluation run. This is to exclude
own animal performance, which would have been affected by grazing treatment. The overall EBI differed between genotypes, with HF at €115, JEX at €131 and 3WAY at €159.
Table 3.2 Mean Economic Breeding Index (EBI) and sub-indices for each cow genotype.

<table>
<thead>
<tr>
<th></th>
<th>HF(^1)</th>
<th>JEX</th>
<th>3WAY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EBI(^2)</strong></td>
<td>115</td>
<td>131</td>
<td>159</td>
</tr>
<tr>
<td><strong>Sub-indices</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk</td>
<td>38.7</td>
<td>52.1</td>
<td>43.4</td>
</tr>
<tr>
<td>Fertility</td>
<td>42.1</td>
<td>30.7</td>
<td>62.5</td>
</tr>
<tr>
<td>Health</td>
<td>1.5</td>
<td>0.7</td>
<td>4.0</td>
</tr>
<tr>
<td>Calving</td>
<td>31.6</td>
<td>33.6</td>
<td>37.2</td>
</tr>
<tr>
<td>Beef</td>
<td>-8.9</td>
<td>-27.6</td>
<td>-16.7</td>
</tr>
<tr>
<td>Maintenance</td>
<td>8.5</td>
<td>36.5</td>
<td>25.9</td>
</tr>
<tr>
<td>Management</td>
<td>1.2</td>
<td>4.8</td>
<td>2.4</td>
</tr>
</tbody>
</table>

\(^1\)HF = Holstein Friesian, JEX = Jersey × Holstein Friesian, 3WAY = Norwegian Red × Jersey × Holstein Friesian

\(^2\)EBI for each cow was calculated from their parental average EBI taken from the January 2019 Irish Cattle Breeding Federation evaluation run
3.2.3 Reproductive management

Cows were visually observed for oestrus during the breeding season (12 week period) and breeding commenced between 20th to 25th April each year. Tail paint was used as a heat detection aid and AI was used for the first six-weeks by the same professional inseminator followed by natural mating using bulls. All cows were inseminated with thawed, frozen semen, the quality of which had been verified before the start of the breeding season. No synchronisation of cows occurred over the four years. Transrectal ultrasound imaging was used approximately 30 to 36 and 60 to 66 days post-AI to determine pregnancy status and to determine overall pregnancy rates at 150 days after the beginning of the breeding season. The reproductive measurements used were mean calving date, 24 day submission rate (calculated based on animals served within the first 24 days of the breeding season, irrespective of calving date), calving to service interval (interval in days from calving to first service), calving to conception interval (interval in days from calving to conception), pregnancy rate to first service (pregnant to first service and pregnant at the end of the breeding season), six-week pregnancy rate (pregnant at six-weeks of the breeding season and pregnant at the end of the breeding season), number of services (number of AI and natural services per cow during the 12-week breeding season), embryo mortality (ultrasound scan: pregnant at day 30 post-AI but not pregnant at day 60 post-AI, or at the end of the breeding season), and overall pregnancy rate (confirmed by ultrasound scanning 150 days after the start of the breeding season). Bulls were chosen with a calving difficulty of less than 5% for mature cows and less than 2.5% for heifers. Over the four year period, the three genotypes were mated to a total of 40 bulls, of which 22 were HF, eight were Jersey, seven were Norwegian Red and three were other breeds. From 2014 to 2016 50% of HF cows were inseminated with HF straws and 50% were inseminated with Jersey straws. All JEX F1 cows were inseminated with Norwegian Red straws and all 3WAY cows received HF straws.

3.3 Meteorological Data

Mean monthly rainfall and air and soil temperature data for each year of the study and the ten year average are presented in Table 3.3. Weather data was recorded from the national weather station nearest to the experimental site, which was Cork airport. Weather conditions varied amongst all four years of the study. Mean air and soil temperatures for the four years remained consistent with ten year averages. Mean air temperature over the four years was
slightly higher than the previous ten year average (+ 0.3°C); this was also reflected in the mean soil temperature being slightly higher (+ 0.6°C). Rainfall was extremely variable; in 2015, rainfall was 422 mm above the ten year average with May (+ 61 mm), September (+ 85 mm), November (+ 39 mm) and in particular December (+ 261 mm) being the months with higher than average rainfall. Extended periods of adverse weather (e.g. drought or snow) did not occur during the trial period and therefore did not negatively impact this grazing study.
Table 3.3 Meteorological data for the experimental period 2014-2017 compared with the previous ten year average (2004-2013)

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Average</th>
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</thead>
<tbody>
<tr>
<td>Air Temperature (°C)</td>
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<td></td>
<td></td>
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<tr>
<td>2014</td>
<td>6.3</td>
<td>5.9</td>
<td>7.1</td>
<td>9.7</td>
<td>11.3</td>
<td>14.3</td>
<td>16.1</td>
<td>14.1</td>
<td>14.5</td>
<td>11.5</td>
<td>8.9</td>
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<td>2015</td>
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<td>10.3</td>
<td>12.9</td>
<td>13.8</td>
<td>13.7</td>
<td>12.4</td>
<td>11.0</td>
<td>10.1</td>
<td>9.2</td>
<td>9.9</td>
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<tr>
<td>2016</td>
<td>6.8</td>
<td>5.5</td>
<td>6.3</td>
<td>7.4</td>
<td>11.6</td>
<td>14.1</td>
<td>14.6</td>
<td>14.9</td>
<td>13.6</td>
<td>11.2</td>
<td>6.1</td>
<td>7.9</td>
<td>10.0</td>
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<tr>
<td>2017</td>
<td>6.3</td>
<td>6.8</td>
<td>8.0</td>
<td>8.9</td>
<td>11.4</td>
<td>13.6</td>
<td>14.9</td>
<td>14.0</td>
<td>12.6</td>
<td>11.7</td>
<td>7.8</td>
<td>6.3</td>
<td>10.3</td>
</tr>
<tr>
<td>10 year average</td>
<td>5.4</td>
<td>5.5</td>
<td>6.4</td>
<td>8.8</td>
<td>11.4</td>
<td>13.9</td>
<td>15.3</td>
<td>14.8</td>
<td>13.3</td>
<td>10.8</td>
<td>7.4</td>
<td>5.7</td>
<td>9.9</td>
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<tr>
<td>Soil temperature (°C)</td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>2014</td>
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<td>148</td>
<td>72</td>
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<td>148</td>
<td>154</td>
<td>54</td>
<td>127</td>
<td>1,143</td>
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<td>65</td>
<td>95</td>
<td>111</td>
<td>109</td>
<td>1,046</td>
</tr>
</tbody>
</table>
3.4 Sward Measurements

3.4.1 Herbage measurements

Grazing data was collected at each grazing for each treatment. Pre-grazing herbage mass was determined prior to grazing by harvesting two strips (approximately 10 m x 1.2 m) to a height of 4.0 cm using an Etesia mower (Etesia UK Ltd., Warwick UK). The harvested forage was weighed and a 100 g sub-sample was dried at 90°C for 15 hours to determine DM. A combined sample from the two harvested strips was frozen, freeze-dried and milled. These samples were analysed at four time points (February/March, mid-May/mid-June, mid-June/mid-July, September) across the year for DM content, ash content, acid detergent fibre (ADF), neutral detergent fibre (NDF; Van Soest, 1963), crude protein (CP; Chemists, 1990), and OMD (Morgan et al., 1989, as modified by Garry et al., 2018). Throughout the study if extreme values arose from laboratory or field measurements (e.g. inadequate sample mixing, mislabelling, lack of weigh scales calibration etc.), which resulted in outlier data and inflated errors, multiple reanalysis of samples and calibration of all equipment used occurred.

1 unité fourragère lait (UFL) of energy is defined as the net energy content of 1 kg of standard barley for milk production, equivalent to 1,700 kcal. UFL was calculated using the following equation:

\[
UFL \text{ (kcal/kg DM)} = 5.72 \times \text{Protein (g/kg DM)} + 9.5 \times \text{Fat (g/kg DM)} + 4.79 \times \text{Cellulose (g/kg DM)} + 4.17 \times \text{Extracted substances (g/kg DM)} + \text{Constant}
\]

Ten sward heights were taken before and after each strip of forage was harvested using a Jenquip rising platemeter (Jenquip, Fielding, New Zealand), and used to calculate sward density as follows:

\[
\text{Sward density (kg DM/cm)} = \frac{\text{PrGHM}}{\text{pre-cutting height} - \text{post-cutting height}}
\]

Pre-grazing sward height (PrGSH) and PoGSH were also calculated across whole paddocks before and after grazing using a platemeter taking compressed sward heights at 30 locations pre-grazing and 50 compressed sward heights following grazing.
Pre-grazing herbage mass above 4 cm was calculated using sward density according to the following equation:

Pre-grazing herbage mass above 4 cm (kg DM/ha) = (PrGSH - 4 cm) × sward density

3.4.2 Herbage production and utilisation

Herbage production was categorised as grazing herbage production or silage production. All herbage production was recorded and calculated using the online application ‘PastureBase’. Herbage utilised was calculated as follows:

Herbage removed (kg DM/ha) = (PrGSH - PoGSH) x sward density

Herbage utilised (%) = (herbage removed/PrGHM) x 100

Daily herbage allowance and daily herbage removed were then calculated based on the residency time within each paddock. Grazing data were analysed for three periods of the grazing season: spring (turnout to 31st March), summer (1st April to 31st August) and autumn (1st September to housing).

Grazing efficiency = herbage removed (> 4cm)/herbage removed

3.4.3 White clover contribution

White clover content was estimated in each paddock before every grazing event. A Gardena hand shears was used to take 15 random herbage samples cut to 4 cm throughout the paddock. This was mixed and two 70 g cut-samples were weighed and separated by hand into white clover and PRG and other plant fractions, and dried at 60°C for 48 hours to give proportions on a DM basis.
3.5 Animal Measurements

Milk yield was recorded for each cow at each morning (07.00 hours) and evening (15.30 hours) milking and weekly milk production was derived from the individual milk yields (kg) (Dairymaster, Causeway, Co. Kerry, Ireland). Milk fat, protein and lactose content was determined weekly from a consecutive evening and morning milking sample for each cow and was tested using infrared spectrophotometry (MilkoScan 203 (DK-3400), Foss Electric, Hillerød, Denmark). Milk solids yield per cow was also calculated. Milk solids production per kg of BW was calculated by dividing total kg MS/cow per lactation by average BW. Cows were weighed fortnightly during lactation upon exit from the milking parlour using an electronic scale (Tru-Test Ltd., Auckland, New Zealand). Body condition score was assessed fortnightly by the same individual throughout the study on a scale of 1 to 5 in increments of 0.25 (where 1 = emaciated, 5 = extremely fat) as outlined by Edmonson et al. (1989). Calving difficulty was recorded for each cow at calving and ranked on a scale of 1 to 4, (1 = no assistance, 2 = a small amount of handling, 3 = mechanical assistance and 4 = veterinary assistance). Lameness and mastitis were recorded at every event where a cow required treatment. Lameness incidence is reported as the percentage of cows with at least one incidence of lameness in the year. Mastitis is reported as the percentage of cows with at least one case of mastitis per year. The natural logarithm of SCC was used to ensure normally distributed residuals (Walsh et al., 2007).

3.6 Statistical Analysis

3.6.1 Herbage production and dietary details

All data was analysed using SAS 9.4 software (SAS Institute Inc., Cary, NC). Pre-grazing herbage mass, PrGSH, PoGSH, density, herbage DM, weekly growth rate and sward white clover content were analysed using PROC MIXED (SAS Institute Inc., Cary, NC) with year, ploidy, white clover treatment, rotation, and the associated interactions; Ploidy x white clover treatment, year x white clover treatment and year x ploidy x white clover treatment, included in the model. Individual paddock was the experimental unit, with paddock included as a random factor and rotation as a repeated measure. A compound symmetry covariance structure among records within paddock was used. Total herbage DM production, herbage utilised, silage produced and grazed herbage was analysed using PROC MIXED with year, ploidy, white clover treatment and the associated interactions; Ploidy x white clover
treatment, year x white clover treatment and year x ploidy x white clover treatment included in the model. Sward nutritive value was analysed using PROC GLM (SAS Institute Inc., Cary, NC) with year, time point, ploidy, white clover treatment and PRG cultivar included in the model. Concentrate and silage supplementation was analysed using PROC MIXED (SAS Institute Inc., Cary, NC) with cow as the experimental unit taking into account the effects of year, ploidy, white clover treatment, parity, breed and their subsequent interactions. Tukey’s test was used to determine differences between treatment means. Significance was declared at \( P < 0.05 \) and a tendency at \( P > 0.05 \) and \( P < 0.10 \).

### 3.6.2 Milk production per cow and per ha

Animal variables such as daily milk yield, fat, protein and lactose content, daily MS, cumulative milk and MS yield, BW and BCS were analysed using PROC MIXED (SAS Institute Inc., Cary, NC) taking into account the effects of year, ploidy, white clover treatment, parity, breed and their subsequent interactions; year x ploidy x white clover treatment, year x white clover treatment, year x breed and parity x breed. Individual cow was the experimental unit. Lactation length and the EBI sub-index for milk, fat, protein and MS centred within parity and breed were included as covariates in the model for each respective analysis. The lactation was broken down into three distinct periods: Period 1 (corresponding to the first 14 weeks of lactation), Period 2 (corresponding to weeks 15 - 28 of lactation) and Period 3 (corresponding to weeks 29 - 42 of lactation). All three periods were analysed as described previously. For milk, fat, protein, lactose, MS yield and grazing days per ha paddock was the experimental unit and variables were analysed separately using PROC MIXED (SAS Institute Inc., Cary, NC) with the effect of year, location block, ploidy, white clover treatment, number of silage cuts and their interactions included in the model. Tukey’s test was used to determine differences between treatment means. Significance was declared at \( P < 0.05 \) and a tendency at \( P > 0.05 \) and \( P < 0.10 \).

### 3.6.3 Reproductive performance

The responses to different ploidy and white clover treatments on calving date, calving to first service interval, calving to conception interval and number of services per cow were analysed using PROC MIXED (SAS Institute Inc., Cary, NC) taking into account the effects of year,
ploidy, white clover treatment, parity, genotype and their subsequent interactions; year x genotype, genotype x ploidy, genotype x white clover treatment and parity x genotype. Individual cow was the experimental unit. A logistic regression model (PROC LOGISTIC, SAS Institute Inc., Cary, NC) that included the effects of ploidy, white clover treatment, genotype and parity, with the fertility sub-index of the EBI centred within genotype and parity included as a covariate, was used to determine 24 day submission rate, pregnancy rate to first service, pregnancy rate to second service, six-week pregnancy rate, embryo mortality, and overall pregnancy rate.

3.6.4 BW, BCS and health performance

Bodyweight, BCS (mean during lactation, at calving and at drying off) and SCC were analysed using PROC MIXED (SAS Institute Inc., Cary, NC) taking into account the effects of genotype, year, parity, ploidy, white clover treatment and their subsequent interactions; genotype x parity, genotype x year, genotype x ploidy, genotype x white clover treatment. Individual cow was the experimental unit. A mean SCC was calculated for each cow in each year of the experiment by calculating the geometric mean of the SCC for each cow. A logistic regression model (PROC LOGISTIC, SAS Institute Inc., Cary, NC) that included the effects of genotype, parity and grazing treatment was used to determine calving difficulty, lameness incidence and mastitis incidence.
Chapter 4
Milk production per cow and per hectare of spring calving dairy cows grazing swards differing in *Lolium perenne* L. ploidy and *Trifolium repens* L. composition

4.1 Summary

Grazed grass is the cheapest feed available for dairy cows in temperate regions and so to maximise profits, dairy farmers must optimise the utilisation of this high quality feed. Previous research has defined the benefits of including white clover in grass swards for milk production, usually at reduced N usage and stocking rate. The aim of this study was to quantify the responses in milk production of dairy cows when grazing tetraploid or diploid perennial ryegrass (PRG) sown with and without white clover, but without reducing stocking rate or N usage. Four grazing treatments were compared for this study; tetraploid PRG-only swards, diploid PRG-only swards, tetraploid with white clover swards and diploid with white clover swards. Thirty cows were assigned to each treatment and swards were rotationally grazed at a farm level stocking rate of 2.75 cows/ha and a N fertiliser rate of 250 kg/ha annually. Sward white clover content was 23.6% and 22.6% for tetraploid with white clover swards and diploid with white clover swards, respectively. Milk production did not differ between the two ploidies over this four year study, but cows grazing the PRG-white clover treatments had significantly greater milk yields (+ 596 kg/cow per year) and milk solid yields (+ 48 kg/cow per year) compared with cows grazing the PRG-only treatments. The PRG-white clover swards also produced 1,205 kg DM/ha per year more herbage, which was available for conserving and buffer feeding in spring when there was lower pasture availability on PRG-white clover swards due to lower overwinter growth compared to PRG-only swards. Although white clover is generally used in combination with reduced N fertiliser use, this study provides evidence that including white clover in either tetraploid or diploid PRG swards, combined with high levels of N fertiliser can be effectively managed to increase milk production per cow and per ha.
4.2 Introduction

With the fast-growing worldwide demand for dairy products, particularly in developing countries, and the increasing concern over the environmental impact of dairy farming there is a need for not only efficient but also sustainable farming practices (van Vuuren and Chilibroste, 2013). The suitability of Ireland’s climate for forage production has given it a competitive advantage to produce high quality milk from low cost grazed herbage. Grazed PRG is the cheapest feed available for dairy cows, therefore to maximise profits, dairy farmers should utilise this high quality feed where possible (Dillon et al., 2005; Finneran et al., 2012). In suitable temperate regions pasture can make up to 80% of dairy cow’s diets, so the production and utilisation of grazed grass can significantly increase farm profitability (Macdonald et al., 2010). Good grazing management for spring calving milk production systems requires compact calving in spring to match animal demand to pasture supply, along with the optimum stocking rate suited to the land (O'Donovan et al., 2011).

Perennial ryegrass is one of the most important grass species grown in temperate pastoral regions of the world (McGilloway, 2005). Diploid and tetraploid PRG cultivars differ in nutritional value and growth habit, and tetraploid cultivars have been shown to provide a small positive impact on milk production per cow compared to diploid cultivars (Castle and Watson, 1971; Lantinga and Groot, 1996; Wims et al., 2013). The morphological plant differences between PRG ploidies include tetraploid cultivars having a higher proportion of cellular content that provide a higher concentration of water soluble carbohydrates, protein and lipids, and improves digestibility (Smith et al., 2001). Tetraploid cultivars have fewer tillers compared to diploid cultivars but have a much larger leaf size. Previous research has shown a preference for animals to graze tetraploid cultivars compared to diploid cultivars (Balocchi and López, 2010) and for tetraploid cultivars to support higher sward white clover content compared to diploid cultivars under sheep and cattle grazing (Gooding et al., 1996; Stilmant et al., 2005).

White clover inclusion in PRG swards can play a role in sustainable agriculture as its ability to biologically fix N can lead to a reduction in inorganic N fertiliser application rates while maintaining/increasing pasture DM production and pasture nutritive value (Lüscher et al., 2014; Delaby et al., 2016). Recent studies have confirmed that including white clover in PRG
swards can have a positive effect on pasture production as well as animal performance (Enriquez-Hidalgo et al., 2014; Egan et al., 2018) with a milk production increase of 15-20% observed when cows grazed PRG-white clover swards compared to PRG-only swards (Phillips and James, 1998). The increase in milk production has been associated with higher pasture nutritive value from PRG-white clover swards, especially in mid-season compared to PRG (Søegaard, 1993) and an increase in voluntary herbage DMI (Ribeiro Filho et al., 2003), with numerous studies having shown animals to selectively graze white clover over PRG (Gooding et al., 1996; Rutter et al., 2004). A recent meta-analysis reported that cows grazing PRG-white clover swards produced an additional 1.4 kg milk/cow per day than cows grazing PRG-only swards while milk production per ha was similar due to the lower stocking rate and reduced N fertiliser application rates associated with PRG-white clover swards (Dineen et al., 2018). Dineen et al. (2018) hypothesised that increased stocking rates and N fertiliser application rates with PRG-white clover swards could increase productivity from pasture-based production systems. However, the environmental impacts and the negative correlation between N use and white clover persistence would need to be carefully examined (Ledgard et al., 2009).

The objective of this study was to determine the effect of PRG ploidy (tetraploid and diploid) sown with and without white clover, at the same stocking rate and N fertilisation level, on milk production per cow and per ha of grazing dairy cows in a spring calving grass-based production system.

4.3 Materials and Methods

4.3.1 Experimental design and treatments

The experiment was a randomised block design with a 2 x 2 factorial arrangement of treatments creating four grazing treatments, a tetraploid PRG-only sward (TGO), a diploid PRG-only sward (DGO), a tetraploid PRG sward with white clover (TWC) and a diploid PRG sward with white clover (DWC). Further detail of the experimental design and grazing treatments can be found in Chapter 3.
4.3.2 Animal measurements

Milk yield, MS yield, BW and BCS measurements were carried out as described in Chapter 3. The following reproductive performance measurements were recorded as described in Chapter 3: 24 day submission rate, pregnancy rate to first service, pregnancy rate to second service, six-week pregnancy rate, embryo mortality, overall pregnancy rate, calving date, calving to first service interval, calving to conception interval and number of services per cow.

4.3.3 Herbage measurements

The following sward measurements were undertaken at each grazing event as described in Chapter 3: PrGSH, PoGSH, pre-grazing herbage mass, sward density, DM content and sward white clover content.

4.3.4 Statistical analysis

All data was analysed using SAS 9.4 software (SAS Institute Inc., Cary, NC). Individual cow was the experimental unit and the model used took into account the effects of year, ploidy, white clover treatment, parity, breed and their subsequent interactions. Tukey’s test was used to determine differences between treatment means. Significance was declared at P < 0.05 and a tendency at P > 0.05 and P < 0.10, further details can be found in Chapter 3.

4.4 Results

4.4.1 Herbage production and grazing characteristics

The four year average grazing season length was 286 days and 281 days respectively for PRG-only (TGO and DGO) and PRG-white clover (TWC and DWC) treatments. Full days at grass for PRG-only and PRG-white clover groups were 247 days and 240 days, respectively. Weekly herbage growth rate did not vary between the two PRG ploidies. Consequently herbage production did not differ between tetraploid (16,211 kg DM/ha) and diploid (16,136 kg DM/ha) swards seasonally or cumulatively. On average PRG-white clover swards had a higher growth rate over the grazing season (+ 7.3 kg DM/ha per day; 60.9 kg DM/ha per day vs. 53.7 kg DM/ha per day for PRG-white clover and PRG-only swards, respectively; Figure
4.1). Cumulative pasture DM production was significantly increased by white clover inclusion as PRG-white clover swards produced on average 1,205 kg DM/ha per year more than PRG-only swards (15,643 and 15,494 kg DM/ha per year for TGO and DGO, respectively vs. 16,779 and 16,773 kg DM/ha for TWC and DWC per year, respectively). This extra pasture was produced in summer (+ 892 kg DM/ha; 11,576 vs. 12,468 kg DM/ha for PRG-only and PRG-white clover, respectively) and autumn (+ 237 kg DM/ha; 3,055 vs. 3,291 kg DM/ha for PRG-only and PRG-white clover, respectively), with all four grazing treatments having similar pasture production during spring. Perennial ryegrass-white clover swards produced more grazing DM (11,950 vs. 11,320 kg DM/ha; $P = 0.032$) and tended to produce more silage DM (4,826 vs. 4,250 kg DM/ha; $P = 0.075$) than PRG-only swards.
Figure 4.1 Comparison of perennial ryegrass-only (tetraploid and diploid mean) and perennial ryegrass-white clover (tetraploid and diploid mean) swards for daily grass growth (mean 2014-2017)
Diploid and tetraploid white clover swards had similar sward white clover content on average over the four years (23.6% and 22.6%, respectively; Table 4.1). However, there were large variations in sward white clover content between paddocks, seasons and years. White clover content was lowest in February for all four years of the study and highest from August to October (Figure 4.2). White clover content reduced significantly over the four year period as sward white clover content was 36% in 2014, 24% in 2015, 18% in 2016 and 14% in 2017.

The DM content of the swards varied significantly between ploidy, with diploid swards having a consistently higher DM content compared to tetraploid swards (18.8% vs. 17.9%). Diploid swards had a higher PrGHM (1,673 kg DM/ha) than tetraploid swards (1,584 kg DM/ha; Table 4.1) however, their PrGSH did not differ (average 8.80 cm). Tetraploid swards had a lower PoGSH compared to diploid swards (4.10 vs. 4.32 cm; Table 4.1). Diploid swards tended to have a higher density compared to tetraploid swards (332 vs. 326 kg DM/ha per cm; P = 0.074).

Dry-matter content of PRG-white clover swards was significantly lower than PRG-only swards (17.2% vs. 19.4%). Perennial ryegrass-white clover swards had a lower average PrGHM (1,579 kg DM/ha) compared to PRG-only swards (1,678 kg DM/ha) throughout the year. White clover inclusion was associated with a 0.24 cm lower PrGSH compared with PRG-only swards (8.56 vs. 8.80 cm) and including white clover in the swards lowered PoGSH compared to PRG-only swards (3.85 vs. 4.21 cm). Perennial ryegrass-white clover swards had similar sward density compared to PRG-only swards (326 vs. 332 kg DM/ha per cm).
Table 4.1 Comparison of perennial ryegrass ploidy and white clover (WC) inclusion on sward characteristics, grazing efficiency, herbage allowance and herbage removed (mean of 2014-2017)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>TGO</th>
<th>DGO</th>
<th>TWC</th>
<th>DWC</th>
<th>S.E.</th>
<th>Ploidy</th>
<th>WC</th>
<th>Ploidy * WC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-grazing herbage mass (kg DM/ha)</td>
<td>1,631</td>
<td>1,725</td>
<td>1,537</td>
<td>1,620</td>
<td>30.2</td>
<td>0.003</td>
<td>0.001</td>
<td>0.849</td>
</tr>
<tr>
<td>Pre-grazing herbage height (cm)</td>
<td>8.71</td>
<td>8.88</td>
<td>8.54</td>
<td>8.57</td>
<td>0.085</td>
<td>0.199</td>
<td>0.004</td>
<td>0.398</td>
</tr>
<tr>
<td>Post-grazing herbage height (cm)</td>
<td>4.10</td>
<td>4.32</td>
<td>3.78</td>
<td>3.92</td>
<td>0.039</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.271</td>
</tr>
<tr>
<td>Density (kg DM/ha per cm)</td>
<td>329</td>
<td>334</td>
<td>322</td>
<td>329</td>
<td>3.9</td>
<td>0.074</td>
<td>0.098</td>
<td>0.690</td>
</tr>
<tr>
<td>Herbage removed (kg DM/ha)</td>
<td>1,599</td>
<td>1,615</td>
<td>1,618</td>
<td>1,642</td>
<td>27.1</td>
<td>0.433</td>
<td>0.871</td>
<td>0.656</td>
</tr>
<tr>
<td>Grazing efficiency</td>
<td>1.00</td>
<td>0.94</td>
<td>1.09</td>
<td>1.06</td>
<td>0.02</td>
<td>0.022</td>
<td>&lt;0.001</td>
<td>0.357</td>
</tr>
<tr>
<td>Dry-matter (%)</td>
<td>18.8</td>
<td>20.0</td>
<td>16.9</td>
<td>17.5</td>
<td>0.18</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.078</td>
</tr>
<tr>
<td>White clover content (%)</td>
<td>-</td>
<td>-</td>
<td>22.6</td>
<td>23.6</td>
<td>1.17</td>
<td>0.546</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>White clover herbage yield (kg DM/ha)</td>
<td>-</td>
<td>-</td>
<td>305</td>
<td>300</td>
<td>47.2</td>
<td>0.934</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Herbage allowance (kg DM/cow per day)</td>
<td>15.3</td>
<td>16.0</td>
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<td>0.006</td>
<td>0.066</td>
<td>0.966</td>
</tr>
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<td>Spring</td>
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<td>16.8</td>
<td>13.0</td>
<td>13.9</td>
<td>1.05</td>
<td>0.169</td>
<td>&lt;0.001</td>
<td>0.887</td>
</tr>
<tr>
<td>Summer</td>
<td>15.3</td>
<td>16.3</td>
<td>15.2</td>
<td>16.1</td>
<td>0.32</td>
<td>0.003</td>
<td>0.655</td>
<td>0.950</td>
</tr>
<tr>
<td>Autumn</td>
<td>14.9</td>
<td>14.8</td>
<td>14.9</td>
<td>14.9</td>
<td>0.57</td>
<td>0.996</td>
<td>0.895</td>
<td>0.945</td>
</tr>
<tr>
<td>Herbage removed (kg DM/cow per day)</td>
<td>14.9</td>
<td>14.8</td>
<td>15.6</td>
<td>15.8</td>
<td>0.25</td>
<td>0.925</td>
<td>&lt;0.001</td>
<td>0.579</td>
</tr>
<tr>
<td>Spring</td>
<td>15.9</td>
<td>16.3</td>
<td>14.9</td>
<td>15.2</td>
<td>1.16</td>
<td>0.688</td>
<td>0.179</td>
<td>0.919</td>
</tr>
<tr>
<td>Summer</td>
<td>14.4</td>
<td>14.4</td>
<td>15.5</td>
<td>15.9</td>
<td>0.28</td>
<td>0.505</td>
<td>&lt;0.001</td>
<td>0.444</td>
</tr>
<tr>
<td>Autumn</td>
<td>15.1</td>
<td>14.6</td>
<td>15.9</td>
<td>15.5</td>
<td>0.53</td>
<td>0.243</td>
<td>0.070</td>
<td>0.964</td>
</tr>
</tbody>
</table>

1TGO = Tetraploid grass only, DGO = Diploid grass only, TWC = Tetraploid white clover, DWC = Diploid white clover 2Spring = 1st January – 7th April; Summer = 8th April – 31st August; Autumn= 1st September – 31st December
Figure 4.2 Sward white clover content for tetraploid perennial ryegrass-white clover and diploid perennial ryegrass-white clover swards 2014-2017
4.4.2 Dietary details and nutritive value

There was no interaction between ploidy and white clover inclusion. Diploid swards provided a higher herbage allowance than tetraploid swards (15.8 vs. 15.1 kg DM/cow per day, respectively) with the responses observed during summer (16.2 vs. 15.3 kg DM/cow per day, respectively) but not in spring and autumn (Table 4.1). Tetraploid and diploid swards had similar average herbage removed levels across for each season and across the full year. Tetraploid swards achieved a higher grazing efficiency compared to diploid swards (1.04% vs. 1.00%), due to their lower PoGSH. Tetraploid swards had significantly higher UFL values compared to diploid swards (0.89 vs. 0.86 UFL). There were no differences in CP content between the ploidies but diploid swards had higher NDF (+ 21.2 g/kg DM), ADF and ash content, whereas tetraploid swards had higher OMD content (792 vs. 780 g/kg DM), representing an average OMD difference of 11.3 g/kg DM (Table 4.2).

There was a tendency ($P = 0.066$) for PRG-white clover swards to have a lower herbage allowance across the grazing season (15.2 kg DM/cow per day) than PRG-only swards (15.7 kg DM/cow per day), with significantly lower herbage allowance for PRG-white clover treatments in spring (13.5 vs. 16.4 kg DM/cow per day). The average herbage removed for PRG-white clover was 15.7 DM/cow per day and 14.9 kg DM/cow per day for PRG-only treatments. Herbage removed differences were most significant in summer with cows removing 15.7 kg DM/cow per day from PRG-white clover swards, compared to PRG-only (14.4 kg DM/cow per day). Perennial ryegrass-white clover swards appeared to have more herbage removed than allowed due to their PoGSH of less than 4 cm, which led to a higher grazing efficiency compared to PRG-only swards (1.08% vs. 0.97%). Perennial ryegrass-white clover swards had higher UFL values compared to PRG only swards (0.90 vs. 0.84 UFL). There was an average increase in crude protein of 34.7 g/kg DM between swards with and without white clover (228.3 vs. 193.6 g/kg DM; Table 4.2). Perennial ryegrass-white clover swards also had a higher OMD content compared to PRG-only swards (796.2 vs. 775.6 g/kg DM, respectively) and subsequently lower NDF and ADF contents (441 vs. 401 g/kg DM NDF and 255 vs. 241 g/kg DM ADF, respectively), with no differences in ash content.
Table 4.2 Comparison of perennial ryegrass ploidy and white clover (WC) inclusion on sward nutritive value (mean of 2014-2017)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>TGO&lt;sup&gt;1&lt;/sup&gt;</th>
<th>DGO</th>
<th>TWC</th>
<th>DWC</th>
<th>S.E.</th>
<th>P-value</th>
<th>WC&lt;sup&gt;2&lt;/sup&gt;</th>
<th>Ploidy* WC</th>
</tr>
</thead>
<tbody>
<tr>
<td>UFL</td>
<td>0.85</td>
<td>0.83</td>
<td>0.92</td>
<td>0.88</td>
<td>0.01</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.207</td>
</tr>
<tr>
<td>Crude protein (g/kg DM)</td>
<td>196</td>
<td>192</td>
<td>230</td>
<td>227</td>
<td>2.56</td>
<td>0.1412</td>
<td>&lt;0.001</td>
<td>0.926</td>
</tr>
<tr>
<td>Organic matter digestibility (g/kg DM)</td>
<td>780</td>
<td>772</td>
<td>804</td>
<td>789</td>
<td>3.12</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.265</td>
</tr>
<tr>
<td>Neutral detergent fibre (g/kg DM)</td>
<td>431</td>
<td>451</td>
<td>390</td>
<td>411</td>
<td>3.55</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.958</td>
</tr>
<tr>
<td>Acid detergent fibre (g/kg DM)</td>
<td>248</td>
<td>262</td>
<td>233</td>
<td>249</td>
<td>2.75</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.770</td>
</tr>
<tr>
<td>Ash (g/kg DM)</td>
<td>116</td>
<td>122</td>
<td>112</td>
<td>121</td>
<td>2.90</td>
<td>0.007</td>
<td>0.380</td>
<td>0.632</td>
</tr>
</tbody>
</table>

<sup>1</sup>TGO = Tetraploid grass only, DGO = Diploid grass only, TWC = Tetraploid white clover, DWC = Diploid white clover;  <sup>2</sup>White clover
4.4.3 Concentrate and silage supplementation

Concentrate supplementation was similar (344 kg DM/cow per year) as cows were fed the same concentrate levels throughout the study. Similar concentrate levels were fed to all treatments in spring, summer and autumn (155, 73 and 114 kg/cow, respectively). However, cows on PRG-white clover swards were fed significantly more silage than cows on PRG-only swards (430 vs. 350 kg DM/cow per year; Table 4.3). This extra silage was primarily fed during the spring in the first three years of the study (additional 109 kg DM silage/cow in the first three years, with no difference in 2017).
Table 4.3 Comparison of perennial ryegrass ploidy and white clover (WC) inclusion on silage supplementation for lactating cows during Spring, Summer and Autumn (mean of 2014-2017)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>TGO(^1)</th>
<th>DGO</th>
<th>TWC</th>
<th>DWC</th>
<th>S.E.</th>
<th>Ploidy</th>
<th>WC</th>
<th>Ploidy *WC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silage supplementation (kg DM/cow)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>361</td>
<td>338</td>
<td>412</td>
<td>447</td>
<td>6.9</td>
<td>0.380</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Spring</td>
<td>170</td>
<td>167</td>
<td>242</td>
<td>245</td>
<td>2.62</td>
<td>0.810</td>
<td>&lt;0.001</td>
<td>0.273</td>
</tr>
<tr>
<td>Summer</td>
<td>42</td>
<td>19</td>
<td>9</td>
<td>7</td>
<td>0.52</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Autumn</td>
<td>148</td>
<td>152</td>
<td>161</td>
<td>195</td>
<td>6.93</td>
<td>0.006</td>
<td>&lt;0.001</td>
<td>0.028</td>
</tr>
</tbody>
</table>

\(^1\)TGO = Tetraploid grass only, DGO = Diploid grass only, TWC = Tetraploid white clover, DWC = Diploid white clover; Spring = 1\(^{st}\) January – 7\(^{th}\) April; Summer = 8\(^{th}\) April – 31\(^{st}\) August; Autumn = 1\(^{st}\) September – 31\(^{st}\) December
4.4.4 Animal production

There was no interaction between PRG ploidy and white clover inclusion for any of the variables analysed. Daily milk yield, fat, protein, lactose content or MS production did not differ significantly between ploidies (Table 4.4). Cumulative milk yield and MS yields was not different between ploidy (5,545 vs. 5,495 kg milk/cow and 463 vs. 458 kg MS/cow for tetraploid and diploid, respectively). Daily milk yields and subsequently daily MS yields were higher from PRG-white clover swards compared to PRG-only (20.1 vs. 18.0 kg/cow and 1.65 vs. 1.49 kg/cow, respectively). Milk fat content did not differ significantly due to white clover inclusion (Table 4.4). However, cows grazing PRG-white clover swards had a lower milk protein content compared to those grazing PRG-only (3.85% vs. 3.80%) and had a significantly higher milk lactose content (4.79% vs. 4.74%). Cows grazing PRG-white clover produced an extra 597 kg milk/cow per year (5,818 vs. 5,221 kg milk/cow) and 48 kg MS/cow per year (484 vs. 437 kg MS/cow, Figure 4.3) compared to PRG-only.
Table 4.4 Effect of perennial ryegrass ploidy and white clover (WC) inclusion on milk production and composition, bodyweight (BW) and body condition score (BCS) (mean of 2014-2017)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>TGO¹</th>
<th>DGO</th>
<th>TWC</th>
<th>DWC</th>
<th>S.E.</th>
<th>Ploidy</th>
<th>WC</th>
<th>Ploidy* WC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily milk yield (kg)</td>
<td>18.0</td>
<td>18.0</td>
<td>20.2</td>
<td>19.9</td>
<td>0.161</td>
<td>0.270</td>
<td>&lt;0.001</td>
<td>0.386</td>
</tr>
<tr>
<td>Milk fat (%)</td>
<td>4.72</td>
<td>4.73</td>
<td>4.68</td>
<td>4.73</td>
<td>0.039</td>
<td>0.464</td>
<td>0.588</td>
<td>0.593</td>
</tr>
<tr>
<td>Milk Protein (%)</td>
<td>3.87</td>
<td>3.83</td>
<td>3.79</td>
<td>3.80</td>
<td>0.017</td>
<td>0.362</td>
<td>0.002</td>
<td>0.163</td>
</tr>
<tr>
<td>Milk lactose (%)</td>
<td>4.75</td>
<td>4.73</td>
<td>4.78</td>
<td>4.79</td>
<td>0.010</td>
<td>0.544</td>
<td>&lt;0.001</td>
<td>0.115</td>
</tr>
<tr>
<td>Daily milk solids² (kg)</td>
<td>1.49</td>
<td>1.48</td>
<td>1.66</td>
<td>1.64</td>
<td>0.012</td>
<td>0.150</td>
<td>&lt;0.001</td>
<td>0.733</td>
</tr>
<tr>
<td>Cumulative milk yield (kg)</td>
<td>5,235</td>
<td>5,208</td>
<td>5,854</td>
<td>5,782</td>
<td>46.65</td>
<td>0.277</td>
<td>&lt;0.001</td>
<td>0.623</td>
</tr>
<tr>
<td>Cumulative milk solids yield (kg)</td>
<td>439</td>
<td>434</td>
<td>487</td>
<td>482</td>
<td>3.55</td>
<td>0.133</td>
<td>&lt;0.001</td>
<td>0.957</td>
</tr>
<tr>
<td>Average BW (kg)</td>
<td>506</td>
<td>493</td>
<td>503</td>
<td>507</td>
<td>3.75</td>
<td>0.226</td>
<td>0.146</td>
<td>0.020</td>
</tr>
<tr>
<td>BW at calving</td>
<td>516</td>
<td>514</td>
<td>516</td>
<td>521</td>
<td>5.50</td>
<td>0.685</td>
<td>0.536</td>
<td>0.502</td>
</tr>
<tr>
<td>Minimum BW during lactation</td>
<td>468</td>
<td>454</td>
<td>460</td>
<td>462</td>
<td>3.68</td>
<td>0.101</td>
<td>0.896</td>
<td>0.031</td>
</tr>
<tr>
<td>BW at drying off</td>
<td>549</td>
<td>533</td>
<td>539</td>
<td>548</td>
<td>4.43</td>
<td>0.430</td>
<td>0.652</td>
<td>0.005</td>
</tr>
<tr>
<td>Average BCS</td>
<td>2.98</td>
<td>2.92</td>
<td>2.96</td>
<td>2.96</td>
<td>0.012</td>
<td>0.030</td>
<td>0.536</td>
<td>0.022</td>
</tr>
<tr>
<td>BCS at calving</td>
<td>3.16</td>
<td>3.16</td>
<td>3.14</td>
<td>3.17</td>
<td>0.017</td>
<td>0.460</td>
<td>0.594</td>
<td>0.415</td>
</tr>
<tr>
<td>Minimum BCS during lactation</td>
<td>2.77</td>
<td>2.71</td>
<td>2.75</td>
<td>2.75</td>
<td>0.015</td>
<td>0.043</td>
<td>0.519</td>
<td>0.028</td>
</tr>
<tr>
<td>BCS at drying off</td>
<td>2.90</td>
<td>2.82</td>
<td>2.88</td>
<td>2.88</td>
<td>0.019</td>
<td>0.024</td>
<td>0.308</td>
<td>0.025</td>
</tr>
</tbody>
</table>

¹TGO = tetraploid grass only, DGO = diploid grass only, TWC = tetraploid white clover, DWC = diploid white clover; ²milk solids = kg fat + protein
Figure 4.3 Daily milk solids yield per cow by lactation week for tetraploid perennial ryegrass (PRG)-only (TGO; ▪), diploid PRG-only (DGO; ▲), tetraploid PRG-white clover (TWC; ♦) and diploid PRG-white clover (DWC; ●) (mean of 2014-2017)
On average over the four years, cow BW was not affected by grazing swards of either ploidy or whether white clover was present or absent (Table 4.4). Bodyweight for all grazing treatments was similar at calving and drying off as well as having a similar minimum BW during lactation. Average BW for all grazing treatments was 502 kg and BW at calving, minimum BW and BW at drying off was 517, 461 and 542 kg, respectively. Cow BCS tended to be higher on average throughout the year when grazing tetraploids (2.97) compared to diploids (2.94). The lower BCS from diploid swards was most evident at drying off ($P = 0.024$).

Table 4.5 shows the responses in milk and MS yield during periods 1, 2 and 3. No difference in milk and MS yield was observed between ploidies in Period 1 or 2. In Period 3 cows grazing tetraploid swards produced more milk (1,316 vs. 1,280 kg) and MS (122 vs. 118 kg) compared to cows grazing diploid swards. White clover inclusion increased milk yield in each period (+ 84 kg in Period 1, + 299 kg in Period 2, and + 207 kg in Period 3) and this response was predominantly from early summer onwards which corresponded to when white clover content started to increase in the sward (Figure 4.2).
Table 4.5 Effect of perennial ryegrass ploidy and white clover (WC) inclusion on milk and milk solids production in Period 1, Period 2 and Period 3 of lactation (mean of 2014-2017).

<table>
<thead>
<tr>
<th></th>
<th>Treatment</th>
<th>Ploidy</th>
<th>WC</th>
<th>Ploidy *WC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TGO(^1)</td>
<td>DGO</td>
<td>TWC</td>
<td>DWC</td>
</tr>
<tr>
<td></td>
<td>S.E.</td>
<td>P-value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Period 1(^2) (Weeks 1-14)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumulative milk yield (kg)</td>
<td>2,168</td>
<td>2,195</td>
<td>2,278</td>
<td>2,253</td>
</tr>
<tr>
<td></td>
<td>19.67</td>
<td>0.950</td>
<td>&lt;0.001</td>
<td>0.177</td>
</tr>
<tr>
<td>Cumulative milk solids(^3) (kg)</td>
<td>173</td>
<td>176</td>
<td>181</td>
<td>179</td>
</tr>
<tr>
<td></td>
<td>1.64</td>
<td>0.866</td>
<td>0.0003</td>
<td>0.188</td>
</tr>
<tr>
<td>Period 2 (Weeks 15-28)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumulative milk yield (kg)</td>
<td>1,816</td>
<td>1,812</td>
<td>2,120</td>
<td>2,105</td>
</tr>
<tr>
<td></td>
<td>18.67</td>
<td>0.609</td>
<td>&lt;0.001</td>
<td>0.762</td>
</tr>
<tr>
<td>Cumulative milk solids (kg)</td>
<td>149</td>
<td>147</td>
<td>173</td>
<td>171</td>
</tr>
<tr>
<td></td>
<td>1.34</td>
<td>0.143</td>
<td>&lt;0.001</td>
<td>0.710</td>
</tr>
<tr>
<td>Period 3 (Weeks 29-43)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumulative milk yield (kg)</td>
<td>1,217</td>
<td>1,173</td>
<td>1,415</td>
<td>1,388</td>
</tr>
<tr>
<td></td>
<td>16.55</td>
<td>0.030</td>
<td>&lt;0.001</td>
<td>0.619</td>
</tr>
<tr>
<td>Cumulative milk solids (kg)</td>
<td>114</td>
<td>109</td>
<td>129</td>
<td>128</td>
</tr>
<tr>
<td></td>
<td>1.30</td>
<td>0.015</td>
<td>&lt;0.001</td>
<td>0.180</td>
</tr>
</tbody>
</table>

\(^1\)TGO = tetraploid grass only, DGO = diploid grass only, TWC = tetraploid white clover, DWC = diploid white clover; \(^2\) Period 1 = weeks 1–14 of lactation, Period 2 = weeks 15–28 of lactation, Period 3 = weeks 29–42 of lactation; \(^3\)milk solids = kg fat + protein
4.4.5 Reproductive performance

Reproductive performance was not affected by any of the treatments and excellent reproductive performance was observed from all grazing treatments. Mean calving date was on average the 5th February for all grazing treatments over the four years. The average 24 day submission rate was 96% for all treatments. The six-week pregnancy rate was 86% on average, with an overall pregnancy rate after 12 week of breeding at 94% (Table 4.6).
Table 4.6 Effect of perennial ryegrass ploidy and white clover (WC) inclusion on reproductive performance (mean of 2014-2017)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>TGO&lt;sup&gt;1&lt;/sup&gt;</th>
<th>DGO</th>
<th>TWC</th>
<th>DWC</th>
<th>S.E.</th>
<th>Ploidy</th>
<th>WC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calving date</td>
<td>5&lt;sup&gt;th&lt;/sup&gt;  Feb</td>
<td>5&lt;sup&gt;th&lt;/sup&gt; Feb</td>
<td>5&lt;sup&gt;th&lt;/sup&gt; Feb</td>
<td>6&lt;sup&gt;th&lt;/sup&gt; Feb</td>
<td>1.2</td>
<td>0.501</td>
<td>0.936</td>
</tr>
<tr>
<td>Calving to service interval (days)</td>
<td>87</td>
<td>87</td>
<td>87</td>
<td>86</td>
<td>1.4</td>
<td>0.615</td>
<td>0.624</td>
</tr>
<tr>
<td>Calving to conception interval (days)</td>
<td>92</td>
<td>96</td>
<td>96</td>
<td>94</td>
<td>1.9</td>
<td>0.587</td>
<td>0.494</td>
</tr>
<tr>
<td>Services per cow (number)</td>
<td>1.32</td>
<td>1.41</td>
<td>1.43</td>
<td>1.44</td>
<td>0.1</td>
<td>0.444</td>
<td>0.281</td>
</tr>
<tr>
<td>24-day submission rate (%)</td>
<td>96</td>
<td>95</td>
<td>96</td>
<td>97</td>
<td>-</td>
<td>0.816</td>
<td>0.517</td>
</tr>
<tr>
<td>Conception rate to 1&lt;sup&gt;st&lt;/sup&gt; service (%)</td>
<td>72</td>
<td>68</td>
<td>66</td>
<td>65</td>
<td>-</td>
<td>0.588</td>
<td>0.205</td>
</tr>
<tr>
<td>Conception rate to 2&lt;sup&gt;nd&lt;/sup&gt; service (%)</td>
<td>63</td>
<td>65</td>
<td>69</td>
<td>70</td>
<td>-</td>
<td>0.899</td>
<td>0.369</td>
</tr>
<tr>
<td>Six week pregnancy rate (%)</td>
<td>89</td>
<td>86</td>
<td>85</td>
<td>85</td>
<td>-</td>
<td>0.545</td>
<td>0.633</td>
</tr>
<tr>
<td>Overall pregnancy rate (%; 12 weeks)</td>
<td>93</td>
<td>96</td>
<td>92</td>
<td>96</td>
<td>-</td>
<td>0.208</td>
<td>0.878</td>
</tr>
<tr>
<td>Embryo mortality (%)</td>
<td>2.54</td>
<td>5.0</td>
<td>2.52</td>
<td>0.85</td>
<td>-</td>
<td>0.819</td>
<td>0.194</td>
</tr>
</tbody>
</table>

<sup>1</sup>TGO = tetraploid grass only, DGO = diploid grass only, TWC = tetraploid white clover, DWC = diploid white clover;
4.4.6 Performance per ha

All treatments had similar cow grazing days per ha (629 days). Similar milk production per ha (12,696 vs. 12,816 kg/ha) and MS production per ha (1,089 and 1,094 kg/ha) was observed from tetraploid and diploid swards, respectively. Fat, protein and lactose yields per ha were also similar between ploidies, as was the grazed grass, silage and total grass harvested per ha in the four years (Table 4.7).

All milk yield per ha parameters responded to the inclusion of white clover as the PRG-white clover treatments supported an additional 1,954 kg milk/ha, 156 kg MS/ha, 88 kg fat/ha and 69 kg protein/ha (Table 4.7) compared to the PRG-only treatments. Silage harvested per ha was not affected by white clover inclusion but grazed grass harvested (+ 656 kg DM/ha) and total grass harvested (+ 970 kg DM/ha) were significantly increased where white clover was included.
### Table 4.7 Effect of perennial ryegrass ploidy and white clover (WC) inclusion on milk production per hectare from grazing and grass harvested per hectare (mean of 2014-2017)

<table>
<thead>
<tr>
<th></th>
<th>Treatment</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TGO(^1)</td>
<td>DGO</td>
</tr>
<tr>
<td>Grazing days (grazing cow days/ha)</td>
<td>613</td>
<td>629</td>
</tr>
<tr>
<td>Milk yield (kg)</td>
<td>11,596</td>
<td>11,962</td>
</tr>
<tr>
<td>Milk solids yield(^2) (kg)</td>
<td>1,004</td>
<td>1,024</td>
</tr>
<tr>
<td>Fat yield (kg)</td>
<td>559</td>
<td>575</td>
</tr>
<tr>
<td>Protein yield (kg)</td>
<td>444</td>
<td>448</td>
</tr>
<tr>
<td>Lactose yield (kg)</td>
<td>556</td>
<td>569</td>
</tr>
<tr>
<td>Grazed grass harvested (kg DM/ha)</td>
<td>10,169</td>
<td>10,162</td>
</tr>
<tr>
<td>Silage harvested (kg DM/ha)</td>
<td>3,086</td>
<td>3,178</td>
</tr>
<tr>
<td>Total grass harvested (kg DM/ha)</td>
<td>13,255</td>
<td>13,340</td>
</tr>
</tbody>
</table>

\(^1\)TGO = tetraploid grass only, DGO = diploid grass only, TWC = tetraploid white clover, DWC = diploid white clover; \(^2\)milk solids = kg fat + protein
4.5 Discussion

The selection of the correct sward type (i.e. PRG ploidy and cultivar) and whether to include white clover in the sward in temperate grazing systems are two important factors influencing the performance of a grazing system. Dineen et al. (2018) reported when cows grazed PRG-white clover swards, stocking rate and N fertiliser application were reduced by 0.25 cows/ha and 81 kg N/ha, respectively, compared to when cows grazed PRG-only swards. Therefore, while the negative correlation between N use and white clover persistence is well reported (Chapman et al., 2017a; Clark and Harris, 1996; Phelan et al., 2013), along with the environmental impacts of increasing N inputs (Ledgard et al., 2009), the impact of white clover with relatively high N inputs on the productivity of grass-based production systems should be examined. In order to achieve this objective, in this study PRG-white clover swards were compared to PRG-only swards at the same stocking rate (2.75 cows/ha) and N fertiliser rate (250 kg/ha) which is the limit for N fertiliser application in Ireland set under the European Union Nitrates directive.

4.5.1 Sward productivity and utilisation

Although this study reported no effect of PRG ploidy on total or seasonal herbage DM production, there are contrasting reports in the literature as to whether tetraploids or diploids are higher yielding. Balocchi and Lopez (2010) showed that diploid swards had greater herbage DM production compared to tetraploid swards under grazing while Burns et al. (2013) showed, with plots under a simulated conservation management strategy, that tetraploid cultivars out-yielded diploid cultivars. Previous research has shown certain cultivars are more suited to a cutting system than a grazing system (Gilliland et al., 2002). Within this study the combination of grazing management along with silage conservation across all treatments may have negated any effect ploidy might have had on annual herbage DM production.

As reported previously by Guy et al. (2018b), who used the same platform over the initial three years of the experiment, PRG-white clover swards had higher DM yields compared to PRG-only swards. This is in contrast to previous research, where white clover inclusion had no effect on annual herbage DM production (Egan et al., 2018; Enriquez-Hidalgo et al., 2014) or reduced herbage DM production (Humphreys et al., 2009). However, in most of these experiments, chemical N use was reduced to promote BNF from white clover. It has been reported that white
clover can biologically fix up to 200 kg N/ha (Ledgard, 2001; Carlsson and Huss-Danell, 2003), although at lower chemical N fertilisation rates than used in this study. Despite the high level of N fertiliser used in this study (250 kg N/ha), within a subset of paddocks used in this experiment, Guy et al. (2018a) reported a calculated BNF of 151 kg N/ha, demonstrating the potential to retain N fixation even at high applied N levels, which would explain the observed higher growth rates (Figure 4.1) throughout summer and autumn and the extra 1,205 kg DM/ha produced on PRG-white clover swards compared to PRG-only swards. This indicates the benefits of white clover were being gained despite the high N fertiliser regime imposed. However, the extra herbage produced may not have utilised the extra N supplied by BNF, and the potential loss of surplus N on highly stocked farms combined with high levels of artificial N fertiliser is an environmental concern that needs to be considered. A recent review concluded that N leaching does not differ when N is supplied by either BNF or by artificial N, therefore nitrate leaching rates should be calculated using total N in the system and not just artificial N (Chapman et al., 2018). The white clover content of swards and the amount of artificial N applied has been shown to affect the amount of BNF that can occur in the sward (Elgersma et al., 1998; Humphreys et al., 2008). On average over the four years the white clover content was 23.1% despite the high N application rate. Furthermore white clover content did not differ between ploidies, averaging 23.6% and 22.6% for TWC swards and DWC swards, respectively. Both TWC and DWC had similar pre- and post-grazing sward heights throughout the grazing season which reduced the competition for light between PRG and white clover and therefore negated any sward structure effects between PRG ploidies.

The high PrGHM of the diploid swards was similar to previous studies that also reported significantly higher PrGHM for diploid than tetraploids cultivars (Gowen et al., 2003; Wims et al., 2013). Furthermore, the lower PoGSH of tetraploids compared to diploids has previously been observed by Wims et al. (2013). This is associated with their high leaf: stem ratio and higher energy content of tetraploids which can increase grazing efficiency (Balocchi and López, 2010). In addition other studies have shown that cows have a preference for grazing tetraploid over diploid cultivars, which was associated with a longer grazing time, lower PoGSH and the higher digestibility of the tetraploid cultivars (Smith et al., 2001; Stilmant et al., 2005).

In the current study PRG-white clover swards had significantly lower PrGHM than the PRG-only swards which was similar to previous studies (Schils et al., 2000b; Ribeiro Filho et al.,
though, Egan et al. (2018) found no significant differences in PrGHM across the grazing season. Similar to this study, Egan et al. (2018) reported lower PrGHM in rotation one in spring due to lower winter growth rates from PRG-white clover swards but this wasn’t reflected throughout the remainder of the year. The lower PrGHM in spring was due to the lower overwinter herbage growth rate which is a characteristic difference between PRG-white clover swards compared to PRG-only swards, as reported by Lüscher et al. (2001) and Guy et al. (2018a). Over-winter growth (growth in December and January) in this study was 3.5 and 6.3 kg DM/day for PRG-white clover and PRG-only swards on average over the experimental period. This led to a lower opening AFC in Spring, reduced herbage availability and a lower daily herbage allowance for PRG-white clover treatments compared to PRG-only treatments. As a consequence increased supplement, in the form of baled silage, was required for cows grazing the PRG-white clover swards in spring (Table 4.3). This additional silage fed (+ 80 kg DM/cow per year) was produced within each treatment, as PRG-white clover swards harvested an additional 114 kg DM of silage per cow per year. Although harvested silage was not significantly different between treatments, it did cover the additional silage required in PRG-white-clover treatments in spring. Increased supplementation will lead to increased production costs which must be minimised in low-cost grazing systems (Dillon et al., 2005).

The observation that including white clover significantly lowered the PoGSH is corroborated by previous studies that show cows actively selecting white clover over PRG in swards (Rutter et al., 2002; Rutter et al., 2004; Cosgrove et al., 2006). Several studies have shown that cow preference for white clover is the determining factor in lower PoGSH (Phillips and James, 1998; Ribeiro Filho et al., 2005) and it has been hypothesised that this is due to the prehensibility of the mixed forage and a higher OMD content in white clover swards. The expected overall effect would be a lower resistance to chewing and subsequently a higher passage rate of forage through the rumen (Søegaard, 1993; Enriquez-Hidalgo et al., 2018).

4.5.2 Animal production

In this four year study, daily or total milk yield did not differ between cows grazing either ploidy, although there was a tendency for cows grazing tetraploid swards to have greater daily and total MS yield. Tetraploid PRG-only and DGO swards were managed similarly and although DGO had a higher PrGHM and subsequent daily herbage allowance, herbage removed was
similar. While the differences observed between TGO and DGO in terms of sward nutritive value were significant, they were biologically small and therefore the lack of a ploidy effect on milk yield was unsurprising. There is conflicting evidence of the effect of ploidy on milk production per cow, with some studies showing increased milk yield for cows grazing tetraploid compared to diploid swards (Castle and Watson, 1971; Lantinga and Groot, 1996; Wims et al., 2013), whereas other studies have shown no difference in production between cows grazing different ploidies (Gowen et al., 2003; O’Donovan and Delaby, 2005). Gowen et al (2003) reported no overall difference in milk yield between ploidy groups, however, cows grazing one tetraploid cultivar produced more milk than cows grazing the other three cultivars. This may indicate that variations between individual cultivars can be greater than between ploidies (Tubritt et al., 2018) and that the beneficial effects of individual cultivars may only be seasonally expressed (Wims et al., 2013). This is supported by the fact that in Period 3, corresponding to late lactation and autumn, cows grazing tetraploid swards produced more milk and MS than those grazing diploid swards.

The observed significant increase in daily milk yield and MS yield when cows grazed PRG-white clover swards compared to PRG-only swards agrees with numerous previous studies (Ribeiro-Filho et al., 2003; Enriquez-Hidalgo et al., 2014; Egan et al., 2018). These studies observed varying increases in milk production from PRG-white clover swards at lower artificial N application rates (90-150 kg N/ha) to the current study. Egan et al. (2018) studied milk production from cows grazing PRG-white clover receiving 150 kg N/ha or 250 kg N/ha and PRG-only swards receiving 250 kg N/ha. The study found that cows grazing either of the PRG-white clover swards produced more milk (+ 214 kg/cow per year) and MS (+ 34 kg/cow per year) compared to PRG-only swards.

The difference in milk production from the PRG-white clover swards was observed from May onwards in each year (Figure 4.3). This is consistent with white clover content in the sward increasing as the season progresses (Figure 4.2) and is similar to other studies (Schils et al., 2000b; Woodward et al., 2001). The increase in milk production is typically based on two factors; an increase in DMI and an increase in herbage nutritive value in PRG-white clover swards compared to PRG-only swards. In this study herbage removed (an estimate of grass eaten per cow) was 0.8 kg/cow per day greater for cows grazing PRG-white clover swards compared
to PRG-only swards over the grazing season. This was due to the lower PoGSH associated with PRG-white clover swards as herbage allowance was similar for all grazing treatments (Table 4.1). Ribeiro Filho et al. (2003) reported a 1.5 kg DM/day increase in DMI for cows grazing PRG-white clover swards compared to PRG-only swards and Egan et al. (2017) reported an 8% increase in DMI in July when sward white clover content was highest. Andrews et al. (2007) stated that sward white clover content needs to be greater than 20% in order to see an animal production response. This study is in agreement as herbage removed was greater in summer and autumn, when sward white clover content was greatest, with no difference in herbage removed in spring when sward white clover content was lower (Figure 4.2). When total feed intake/cow (grazed grass, concentrate and silage supplementation) during lactation is calculated, PRG-white clover cows consumed 320 kg more DM than PRG-only cows (4,709 vs. 4,389 kg DM/cow, respectively). Using a milk production response of 9.7 kg DM consumed per kg MS produced (4,709 kg DM eaten/485 kg MS/cow) it can be calculated that 32 kg MS or 68% of the increase in MS produced was due to increased DMI with the remaining 32% likely due to the increase in sward nutritive value and associated benefits such as the faster breakdown and passage of white clover through the rumen Minson (1990). White clover inclusion increased sward OMD and CP content and reduced NDF content similar to Ribeiro Filho et al. (2003) and Enriquez-Hidalgo et al. (2018). Previous studies have reported increases of up to 40 g/kg DM of CP content compared to PRG-only swards (Cosgrove et al., 2006; Rodriguez, 2016; Enriquez-Hidalgo et al., 2018) which is similar to the increase observed in this study. The reduced NDF content of the PRG-white clover swards could also be a factor contributing to the increased milk production associated with PRG-white clover swards as the rate and extent of NDF digestion in the rumen can have a major impact on the energy available from forage (Oba and Allen, 1999).

In spring-calving grass-based systems calving cows compactly to match grass production with herd demand is critical to farm profitability (Shalloo et al., 2014). In this study, the overall level of reproductive performance was high and is reflective of excellent reproductive management and the use of high EBI animals (Berry et al., 2007). There was no effect of ploidy or white clover inclusion on reproductive performance which also corresponds to similar BW and BW loss during lactation from all treatments. This indicates all treatments were managed similarly. Although there was a significant effect of ploidy on a number of BCS variables, the differences in BCS were biologically small and subsequently had no impact on reproductive performance. Cows grazing PRG-white clover swards did not have lower BCS despite the increase milk
production, indicating that the increase in milk production was not due to greater mobilisation of body reserves.

4.5.3 Performance per ha

Milk production per ha is an important indicator of the efficiency of grazing systems when land availability and accessibility can be a major limiting factor. Previous studies have shown milk production per ha to increase linearly with stocking rate (Macdonald et al., 2008; McCarthy et al., 2013). Stocking rates in pasture-based systems are typically a reflection of a farm’s ability to grow and utilise the correct amount of herbage to match their stock’s demand. In this study all grazing treatments were stocked at 2.75 cows/ha; therefore as individual animal performance varied, subsequently production/ha also varied. In this case, the PRG-white clover swards produced 1,205 kg DM/ha and utilised 970 kg DM/ha more herbage than PRG-only swards. This increase in grazed grass utilised is the main reason for the increase in milk production per ha for PRG-white clover treatments. However, as the bulk of this additional herbage production was grown in summer when herbage growth rates were already exceeding animal demands, the benefits were largely captured as silage and so managing higher stocking rates could prove difficult in the spring and autumn. This link between grazed grass utilised and farm profitability has been recently reported, suggesting a further advantage for PRG-white clover swards compared to PRG-only (Hanrahan et al., 2018). Furthermore grazed forage is the cheapest form of feed for dairy cows (Dillon et al., 2005); therefore increasing milk production from grazed forage can lower costs and possibly increase profitability. Ultimately farm profitability mainly relies on milk production per cow, stocking rate and pasture utilisation, so the higher milk production and pasture utilisation with the PRG-white clover grazing swards even under a high N regime should be more profitable than PRG-only swards. Further analysis is required to measure what financial costs and benefits could be gained by a farm business using PRG-white clover swards.

4.6 Conclusion

There was no overall significant effect on dairy cow milk production by grazing either tetraploid or diploid swards, but the inclusion of white clover with either ploidy significantly increased milk and MS production by 597 kg milk/cow per year and 48 kg MS/cow per year. This
indicates a huge potential to use white clover in high N grazing dairy systems to increase milk production output. With an additional 1,205 kg DM/ha of herbage DM also produced per year, it was possible to conserve more herbage to supplement for the lower over-winter growth rate of the PRG-white clover swards. These results indicate the potential benefits of utilising white clover in grazing dairy systems and also the practical implications of such a system. However, the environmental implications of using white clover in a high N application system need to be investigated further.
Chapter 5
An assessment of the production, reproduction and functional traits of Holstein-Friesian, Jersey x Holstein-Friesian and Norwegian Red x Jersey x Holstein-Friesian dairy cows in pasture-based systems

5.1 Summary
Pasture-based production systems typically require highly fertile, healthy and robust genetics with greater emphasis on milk solids (kg fat + protein; MS) production as opposed to milk yield. This study assessed milk production, production efficiency, reproductive performance, body weight, body condition score, and incidences of calving difficulty, mastitis and lameness of three different dairy cow genotypes; Holstein-Friesian (HF), Jersey × HF (JEX) and a 3-way cross consisting of 50% Norwegian Red, 25% Jersey and 25% HF (3WAY). The three genotypes were rotationally grazed on four different grazing treatments after calving in spring and were stocked at a rate of 2.75 cows/ha. Holstein-Friesian cows produced higher daily and total milk yields compared to JEX and 3WAY cows (5,718 vs. 5,476 and 5,365 kg/cow, respectively; $P < 0.001$). However, JEX and 3WAY had higher milk fat and protein content (4.86% and 4.75% and 3.87% and 3.88%, respectively) compared to HF (4.52% and 3.72%; $P < 0.001$), resulting in similar MS yield for JEX and HF, (469 and 460 kg/cow) and slightly lower ($P = 0.003$) MS from 3WAY (453 kg/cow) compared to JEX. As parity increased milk and MS yield per cow increased ($P < 0.001$). Reproductive performance was not significantly different between the three genotypes with similar 24 day submission rates, six-week pregnancy rates and overall pregnancy rates over the four year period. No difference in calving difficulty, incidence of mastitis or incidence of lameness was observed between the three genotypes. Bodyweight was significantly different ($P < 0.001$) between all three genotypes with HF being the heaviest followed by 3WAY and JEX (530, 499 and 478 kg, respectively) and 3WAY cows had a higher BCS throughout lactation ($P < 0.001$) compared to HF and JEX. The differences in BW coupled with similar MS production, resulted in JEX having the highest production efficiency (0.98 kg MS/kg BW), 3WAY being intermediate (0.91 kg MS/kg BW) and HF the lowest (0.87 kg MS/kg BW; $P < 0.001$). In conclusion, HF herds with poor reproductive performance and low milk fat and protein contents are likely to benefit considerably from crossbreeding with Jersey, and all herds are likely to benefit in terms of production efficiency. However, where herd performance, particularly in relation to reproductive performance, is comparable with HF in the current study,
crossbreeding with Jersey or Norwegian Red is unlikely to lead to significant improvements in overall herd performance.
5.2 Introduction

The historical decline in reproductive performance of dairy cows, and Holstein-Friesian (HF) in particular, has been linked to selection based mainly on milk production (Lucy, 2001; Dillon et al., 2003). While current breeding strategies have placed greater emphasis on functional traits (mainly reproduction and health) and generally halted the decline in reproductive performance (Miglior, et al., 2017; Cole and Van Raden, 2018; Lucy, 2019), the variation in emphasis on reproduction traits among breeding strategies has meant that improved reproductive performance is not evident in all countries (Pryce et al., 2014). In Ireland, spring calving pasture-based dairy production systems predominate and 90% of dairy cows are HF (DAFM, 2018). Pasture-based dairy systems require compact calving in spring (achieved by attaining high pregnancy rates within a short interval after the start of the breeding season (Berry et al., 2013)) and robust animals (Friggens et al., 2017) in order to produce milk efficiently from pasture (Shalloo et al., 2014).

Considerable evidence exists to demonstrate favourable animal performance benefits from crossbreeding (Buckley et al., 2014) using a range of breeds and across a diversity of production environments (Heins et al., 2006; Prendiville et al., 2011a). Delaby et al. (2018) postulated that crossbreeding could provide a “better balance” to produce robust animals due to a combination of breed complementarity and heterosis. Within pasture-based systems, both internationally and in Ireland, Jersey has been the predominant breed used to cross with HF. In addition to improvements in milk production traits (milk fat and protein content and milk solids (kg fat + protein; MS) yield), reproductive performance and longevity, crossbreeding with Jersey offers advantages relating to intake capacity and production efficiency (Mackle et al., 1996; Prendiville et al., 2009). This combination of characteristics lends the breed particularly suitable for crossbreeding within the context of Ireland’s seasonal pasture-based system with a largely export driven commodity-based product portfolio and this has been substantiated by Prendiville et al. (2011b). Similar results were observed in Northern Ireland and Australia (Auldist et al., 2007; Vance et al., 2013). Crossbreds of Montbéliarde, Normande and Norwegian Red with HF have also been shown to have superior reproductive performance with comparable MS production to their HF contemporaries (Heins et al., 2006; Walsh et al., 2007; Begley et al., 2009).
Lopez-Villalobos et al. (2000) hypothesised that a 3-way rotational crossing system could increase profitability for pasture-based systems in New Zealand. While the theoretical advantages of a three-breed rotational crossing system are clear, data to recommend it in practice is very limited. The advantage in theory lies in the maximisation of hybrid vigour in later generations compared with a two-way reciprocal mating strategy. Recently 3-way rotational crossing has been shown to improve reproductive performance compared to purebred Holsteins in the USA (Hazel et al., 2014; Shonka-Martin et al., 2018). Ferris et al. (2018) reported similar MS production and improved functional traits (lower mastitis and ovarian dysfunction incidences) for a 3-way cross of Swedish-Red x Jersey/Holstein compared with pure Holstein cows; however, this study only comprised a single lactation.

The objective of this study was to investigate the performance of three dairy cow genotypes; HF, Jersey x HF (JEX) and Norwegian Red × JEX cross (3WAY) and parity in terms of milk production, production efficiency, reproductive performance, BW and BCS profiles and functional traits throughout lactation over a four year period in a pasture-based spring calving system.

5.3 Materials and Methods

5.3.1 Experimental design and treatments

The experiment was a randomised block design with a 2 x 2 factorial arrangement of treatments creating four grazing treatments, a tetraploid PRG-only sward (TGO), a diploid PRG-only sward (DGO), a tetraploid PRG sward with white clover (TWC) and a diploid PRG sward with white clover (DWC). Every year each grazing treatment was grazed by 30 cows. Further detail of the experimental design and grazing treatments can be found in Chapter 3.

5.3.2 Animals

As described in Chapter 3, three cow genotypes were used for this experiment HF, JEX and 3WAY. The JEX cows were produced from HF cows mated with a Jersey sire to produce an F1 crossbred animal. The 3WAY cows were produced from F1 JEX cows mated with a Norwegian Red sire. Each year a minimum of three high EBI HF, Jersey and Norwegian Red sires were used. Every year ten cows of each genotype were assigned to one of the four grazing treatments.
described in Chapter 3 and balanced for parity (1, 2 or 3+), calving date, BW, BCS and EBI, giving a single combined herd of 30 cows per grazing treatment and a total of 40 cows of each genotype on the experiment. Further details can be found in Chapter 3. A total of 472 lactations from 242 spring calving dairy cows were used (35, 24, 24, and 24 primiparous and 81, 93, 95 and 96 pluriparous in 2014, 2015, 2016 and 2017, respectively; Table 5.1). The EBI of each genotype is shown in Table 5.2. The EBI and predicted transmitting ability (PTA) for each cow was calculated as the parental average EBI from the January 2019 Irish Cattle Breeding Federation (ICBF) evaluation run. This is to exclude own animal performance, which would have been affected by grazing treatment. The overall EBI differed between genotypes, with HF at €115, JEX at €131 and 3WAY at €159.

5.3.3 Animal measurements

Milk yield, MS yield, BW and BCS measurements were carried out as described in Chapter 3. The following reproductive performance measurements were recorded as described in Chapter 3: 24 day submission rate, pregnancy rate to first service, pregnancy rate to second service, six-week pregnancy rate, embryo mortality, overall pregnancy rate, calving date, calving to first service interval, calving to conception interval and number of services per cow.

5.3.4 Herbage measurements

The following sward measurements were undertaken at each grazing event as described in Chapter 3: PrGSH, PoGSH, pre-grazing herbage mass, sward density, DM content and sward white clover content.

5.3.5 Statistical analysis

All data was analysed using SAS 9.4 software (SAS Institute Inc., Cary, NC). Individual cow was the experimental unit and the model used took into account the effects of year, ploidy, white clover treatment, parity, genotype and their subsequent interactions. Tukey’s test was used to determine differences between treatment means. Significance was declared at P < 0.05 and a tendency at P > 0.05 and P < 0.10, further details can be found in Chapter 3.
Table 5.1 Number of cows of each genotype each year and lactation records within each genotype during the experiment

<table>
<thead>
<tr>
<th>Animals</th>
<th>HF$^1$</th>
<th>JEX</th>
<th>3WAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>39</td>
<td>39</td>
<td>38</td>
</tr>
<tr>
<td>2015</td>
<td>39</td>
<td>40</td>
<td>38</td>
</tr>
<tr>
<td>2016</td>
<td>40</td>
<td>40</td>
<td>39</td>
</tr>
<tr>
<td>2017</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Lactation Records (number)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parity 1</td>
<td>36</td>
<td>36</td>
<td>35</td>
</tr>
<tr>
<td>Parity 2</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Parity 3 +</td>
<td>82</td>
<td>83</td>
<td>80</td>
</tr>
</tbody>
</table>

$^1$HF = Holstein Friesian, JEX = Jersey × Holstein Friesian, 3WAY = Norwegian Red × Jersey × Holstein Friesian
Table 5.2 Mean Economic Breeding Index (EBI), sub-indices and predicted transmitting abilities (PTA) for each cow genotype.

<table>
<thead>
<tr>
<th></th>
<th>HF(^1)</th>
<th>JEX</th>
<th>3WAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBI(^2)</td>
<td>115</td>
<td>131</td>
<td>159</td>
</tr>
<tr>
<td>Sub-indices</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk</td>
<td>38.7</td>
<td>52.1</td>
<td>43.4</td>
</tr>
<tr>
<td>Fertility</td>
<td>42.1</td>
<td>30.7</td>
<td>62.5</td>
</tr>
<tr>
<td>Health</td>
<td>1.5</td>
<td>0.7</td>
<td>4.0</td>
</tr>
<tr>
<td>Calving</td>
<td>31.6</td>
<td>33.6</td>
<td>37.2</td>
</tr>
<tr>
<td>Beef</td>
<td>-8.9</td>
<td>-27.6</td>
<td>-16.7</td>
</tr>
<tr>
<td>Maintenance</td>
<td>8.5</td>
<td>36.5</td>
<td>25.9</td>
</tr>
<tr>
<td>Management</td>
<td>1.2</td>
<td>4.8</td>
<td>2.4</td>
</tr>
<tr>
<td>PTA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk kg</td>
<td>44</td>
<td>-87.1</td>
<td>-76</td>
</tr>
<tr>
<td>Fat kg</td>
<td>6.8</td>
<td>10.5</td>
<td>7.8</td>
</tr>
<tr>
<td>Protein kg</td>
<td>4.9</td>
<td>3.8</td>
<td>3.5</td>
</tr>
<tr>
<td>Fat %</td>
<td>0.08</td>
<td>0.24</td>
<td>0.19</td>
</tr>
<tr>
<td>Protein %</td>
<td>0.06</td>
<td>0.12</td>
<td>0.11</td>
</tr>
</tbody>
</table>

\(^1\)HF = Holstein Friesian, JEX = Jersey × Holstein Friesian, 3WAY = Norwegian Red × Jersey × Holstein Friesian

\(^2\)EBI for each cow was calculated from their parental average EBI taken from the January 2019 Irish Cattle Breeding Federation evaluation run
5.4 Results

Mean grazing characteristics and herbage nutritive values for each year are shown in Table 5.3. Pre-grazing herbage mass was 1,629 kg DM/ha on average over the four years, which was above the target of 1,500 kg DM/ha with some variation among years. Post-grazing sward height was consistently close to the target of 4 cm. Daily herbage allowance and total estimated feed allowance were 15.4 and 17.0 kg DM/cow per day on average over the four years. Nutritive value of the swards over the four years was excellent with an average CP content of 211 g/kg, OMD content of 786 g/kg and NDF content of 421 g/kg.
Table 5.3 Mean grazing characteristics and herbage nutritive values per year across all four grazing treatments

<table>
<thead>
<tr>
<th></th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-grazing herbage mass (kg DM/ha)</td>
<td>1,753</td>
<td>1,637</td>
<td>1,586</td>
<td>1,538</td>
</tr>
<tr>
<td>Herbage allowance (kg DM/ha per day)</td>
<td>15.5</td>
<td>16.2</td>
<td>14.3</td>
<td>15.6</td>
</tr>
<tr>
<td>Total feed allowance (kg DM/ha per day)</td>
<td>17.1</td>
<td>17.4</td>
<td>16.2</td>
<td>17.4</td>
</tr>
<tr>
<td>Post-grazing sward height (cm)</td>
<td>4.13</td>
<td>4.19</td>
<td>3.99</td>
<td>3.81</td>
</tr>
<tr>
<td>Crude Protein (g/kg)</td>
<td>218</td>
<td>216</td>
<td>211</td>
<td>199</td>
</tr>
<tr>
<td>Organic matter digestibility (g/kg)</td>
<td>764</td>
<td>789</td>
<td>781</td>
<td>810</td>
</tr>
<tr>
<td>Neutral detergent fibre (g/kg)</td>
<td>473</td>
<td>393</td>
<td>416</td>
<td>402</td>
</tr>
<tr>
<td>Acid detergent fibre (g/kg)</td>
<td>270</td>
<td>238</td>
<td>248</td>
<td>236</td>
</tr>
<tr>
<td>Ash (g/kg)</td>
<td>136</td>
<td>117</td>
<td>111</td>
<td>107</td>
</tr>
</tbody>
</table>
5.4.1 Milk production

The effect of cow genotype on milk production is presented in Table 5.4, with significant differences among genotypes observed for all variables with the exception of total protein yield \((P > 0.05)\). Lactation length varied amongst genotype with JEX having a longer lactation length of 285 days compared to 3WAY (280 days, \(P = 0.031\)) with HF being intermediate (283 days), due to JEX having an earlier mean calving date. Daily milk yield per cow was significantly higher for HF compared to the two crossbreds which had similar daily yields (19.7 vs. 18.9 and 18.5 kg/cow per day for HF, JEX and 3WAY, respectively; Figure 5.1). Total milk yield per cow was significantly higher for HF compared to the two crossbreds which were similar (Table 5.4). Jersey x Holstein-Friesian and 3WAY had similar milk fat and protein contents which were significantly higher than HF \((P < 0.001)\). Total fat yield was highest for JEX, with HF and 3WAY having similar total fat yields (261 vs. 252 and 250 kg/cow for JEX, HF and 3WAY, respectively). Total MS yield (milk fat + protein) was influenced by genotype with JEX and HF having similar total MS yield of 469 and 460 kg MS/cow, respectively, with the JEX having significantly higher MS compared to 3WAY (453 kg MS/cow, Figure 5.2). The most efficient genotype in terms of MS per kg BW was JEX, followed by 3WAY and then HF.

Parity had a significant effect \((P < 0.001)\) on all milk yield variables analysed with the exception of milk fat content (Table 5.7). Milk and MS yield increased with parity (4,822, 5,631 and 6,105 kg milk/cow and 400, 468 and 513 kg MS/cow for parity 1, 2 and 3+ cows, respectively). There was an interaction between genotype and parity \((P = 0.003)\) for milk yield per cow. There was no difference between genotypes for milk yield among parity 1 animals but there were significant differences evident among parity 2 and 3+ animals. Similar trends in fat content were observed for each genotype from parity 1 to 3+, and subsequently no genotype by parity interaction occurred. Protein content for each genotype increased linearly with parity. Milk solids production was affected by parity with total MS yield increasing with parity, but no interaction between parity and genotype for MS yield was observed.
Table 5.4 Effect of cow genotype on milk production parameters per cow

<table>
<thead>
<tr>
<th></th>
<th>HF&lt;sup&gt;1&lt;/sup&gt;</th>
<th>JEX</th>
<th>3WAY</th>
<th>S.E.</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lactation length (days)</td>
<td>283&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>285&lt;sup&gt;a&lt;/sup&gt;</td>
<td>280&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.4</td>
<td>0.032</td>
</tr>
<tr>
<td>Total milk yield (kg/cow)</td>
<td>5,720&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5,476&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5,366&lt;sup&gt;b&lt;/sup&gt;</td>
<td>43.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total SCM (kg/cow)</td>
<td>5,827&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5,905&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5,681&lt;sup&gt;b&lt;/sup&gt;</td>
<td>41.3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Fat content (%)</td>
<td>4.52&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.86&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.75&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.038</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Protein content (%)</td>
<td>3.72&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.87&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.88&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.017</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lactose content (%)</td>
<td>4.74&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.82&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.73&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.009</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total fat yield (kg/cow)</td>
<td>252&lt;sup&gt;a&lt;/sup&gt;</td>
<td>261&lt;sup&gt;b&lt;/sup&gt;</td>
<td>250&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total protein yield (kg/cow)</td>
<td>208</td>
<td>208</td>
<td>204</td>
<td>1.5</td>
<td>0.068</td>
</tr>
<tr>
<td>Total lactose yield (kg/cow)</td>
<td>273&lt;sup&gt;a&lt;/sup&gt;</td>
<td>266&lt;sup&gt;b&lt;/sup&gt;</td>
<td>256&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total milk solids yield (kg/cow)</td>
<td>460&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>469&lt;sup&gt;a&lt;/sup&gt;</td>
<td>453&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.3</td>
<td>0.004</td>
</tr>
<tr>
<td>Total milk solids yield/BW</td>
<td>0.87&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.98&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.91&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.01</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

<sup>1</sup>HF = Holstein Friesian, JEX = Jersey × Holstein Friesian, 3WAY = Norwegian Red × Jersey × Holstein Friesian
Figure 5.1 Four year mean comparison of the daily milk solids yield of Holstein-Friesian (HF) cows with that of Jersey x HF (JEX) and Norwegian Red x Jersey x HF (3WAY) crossbred cows, (2014 – 2017)
Figure 5.2 Four year mean comparison of the daily milk yield of Holstein-Friesian (HF) cows with that of Jersey x HF (JEX) and Norwegian Red x Jersey x HF (3WAY) crossbred cows, (2014 – 2017)
5.4.2 Reproductive performance

Grazing treatment did not affect animal reproductive or health performance, and is reported in a Chapter 4. The reproductive performance of the three genotypes is shown in Table 5.5 with only two parameters showing a significant difference between genotypes. Calving date was significantly affected by genotype with JEX having an earlier mean calving date compared to HF and 3WAY (2\textsuperscript{nd} February vs. 6\textsuperscript{th} February and 7\textsuperscript{th} February, respectively ($P = 0.003$). The variation in calving date subsequently led to a difference amongst genotypes for calving to service interval. Calving to service interval was longer for JEX compared to HF and 3WAY (91 vs. 85 and 84 days, respectively). Calving to conception interval, 24 day submission rate, pregnancy rate to first service, six-week pregnancy rate, overall pregnancy rate, number of services and embryo mortality were similar for all genotypes over the four year period ($P > 0.05$). Parity had no effect on six-week pregnancy rate or overall pregnancy rate, and there was no interaction between genotype and parity for the reproductive variables reported (Table 5.7).
Table 5.5 Effect of cow genotype on reproductive performance 2014 – 2017

<table>
<thead>
<tr>
<th></th>
<th>HF(^1)</th>
<th>JEX</th>
<th>3WAY</th>
<th>S.E.</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calving date</td>
<td>6(^{th}) Feb(^a)</td>
<td>2(^{nd}) Feb(^b)</td>
<td>7(^{th}) Feb(^a)</td>
<td>1.12</td>
<td>0.007</td>
</tr>
<tr>
<td>Calving to service interval (days)</td>
<td>85(^a)</td>
<td>91(^b)</td>
<td>84(^a)</td>
<td>1.25</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Calving to conception interval (days)</td>
<td>94</td>
<td>95</td>
<td>93</td>
<td>1.76</td>
<td>0.497</td>
</tr>
<tr>
<td>24 day submission rate (%)</td>
<td>97.5</td>
<td>93.1</td>
<td>97.5</td>
<td>-</td>
<td>0.999</td>
</tr>
<tr>
<td>Pregnancy rate to 1(^{st}) service (%)</td>
<td>65.2</td>
<td>73.0</td>
<td>65.6</td>
<td>-</td>
<td>0.242</td>
</tr>
<tr>
<td>6 week pregnancy rate (%)</td>
<td>88.0</td>
<td>87.4</td>
<td>84.1</td>
<td>-</td>
<td>0.362</td>
</tr>
<tr>
<td>Overall pregnancy rate (%) 12 weeks</td>
<td>96.8</td>
<td>93.1</td>
<td>93.0</td>
<td>-</td>
<td>0.966</td>
</tr>
<tr>
<td>Number of services</td>
<td>1.43</td>
<td>1.33</td>
<td>1.43</td>
<td>0.06</td>
<td>0.436</td>
</tr>
<tr>
<td>Embryo mortality (%)</td>
<td>2.53</td>
<td>2.52</td>
<td>3.18</td>
<td>-</td>
<td>0.999</td>
</tr>
</tbody>
</table>

\(^1\)HF = Holstein Friesian, JEX = Jersey × Holstein Friesian, 3WAY = Norwegian Red × Jersey × Holstein Friesian
5.4.3 BW, BCS and functional trait performance

Bodyweight was significantly different amongst the three genotypes on average throughout lactation and at calving ($P < 0.001$). Holstein-Friesian cows had a consistently higher BW on average, they were 31 kg heavier than 3WAY cows and 52 kg heavier than JEX cows (Table 5.6, Figure 5.3). Bodyweight also differed for parity with parity 1 cows having the lowest BW, followed by parity 2 and 3+, respectively ($P < 0.001$, Table 5.7). Body condition score also differed amongst genotypes with HF and JEX having similar BCS on average over the four years, but 3WAY cows having consistently higher BCS (Figure 5.4). The higher BCS with 3WAY cows was recorded from calving and carried on throughout lactation until drying off. Higher BCS was also observed with greater parity animals as parity 3+ had significantly higher BCS compared to parity 1 and 2 animals (Table 5.7). Functional performance of the cows was recorded using four parameters; calving difficulty on a scale of 1 to 4, lameness incidence (%), mastitis incidence (%) and SCC. There was no significant effect of genotype on any of the functional parameters analysed. First-parity animals had a greater mean SCC (63 cells/ml) than parity 2 and 3+ animals (35 and 42 cells/ml, respectively), however, this did not increase incidence of mastitis (Table 5.6). Lameness incidence increased ($P < 0.001$) as parity increased.
Table 5.6 Effect of cow genotype on BW, BCS and health performance

<table>
<thead>
<tr>
<th></th>
<th>HF(^1)</th>
<th>JEX</th>
<th>3WAY</th>
<th>S.E.</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average BW (kg/cow)</td>
<td>530(^a)</td>
<td>478(^b)</td>
<td>499(^c)</td>
<td>3.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>BW at calving</td>
<td>542(^a)</td>
<td>493(^b)</td>
<td>515(^c)</td>
<td>5.0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>BW at dry off</td>
<td>572(^a)</td>
<td>515(^b)</td>
<td>540(^c)</td>
<td>4.0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Average BCS</td>
<td>2.93(^a)</td>
<td>2.94(^a)</td>
<td>2.99(^b)</td>
<td>0.011</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>BCS at calving</td>
<td>3.14(^a)</td>
<td>3.14(^a)</td>
<td>3.20(^b)</td>
<td>0.016</td>
<td>0.008</td>
</tr>
<tr>
<td>BCS at dry off</td>
<td>2.85(^a)</td>
<td>2.83(^a)</td>
<td>2.92(^b)</td>
<td>0.017</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Calving difficulty (%)</td>
<td>26.6</td>
<td>30.2</td>
<td>25.5</td>
<td>-</td>
<td>0.529</td>
</tr>
<tr>
<td>Calving difficulty 3 (%)</td>
<td>7.0</td>
<td>5.0</td>
<td>4.5</td>
<td>-</td>
<td>0.596</td>
</tr>
<tr>
<td>Lameness (%)</td>
<td>18.4</td>
<td>13.8</td>
<td>15.3</td>
<td>-</td>
<td>0.439</td>
</tr>
<tr>
<td>Mastitis (%)</td>
<td>5.1</td>
<td>6.9</td>
<td>7.6</td>
<td>-</td>
<td>0.906</td>
</tr>
<tr>
<td>Somatic cell count (cells/ml)</td>
<td>50.2</td>
<td>46.5</td>
<td>43.5</td>
<td>3.76</td>
<td>0.450</td>
</tr>
</tbody>
</table>

\(^1\)HF = Holstein Friesian, JEX = Jersey × Holstein Friesian, 3WAY = Norwegian Red × Jersey × Holstein Friesian
Figure 5.3 Four year mean comparison of the bodyweight of Holstein-Friesian (HF) cows with that of Jersey x HF (JEX) and Norwegian Red x Jersey x HF (3WAY) crossbred cows, (2014 – 2017)
Figure 5.4 Four year mean comparison of the body condition score of Holstein-Friesian (HF) cows with that of Jersey x HF (JEX) and Norwegian Red x Jersey x HF (3WAY) crossbred cows, (2014 – 2017)
Table 5.7 Effect of cow genotype and parity on milk production, BW and BCS

<table>
<thead>
<tr>
<th>Parity</th>
<th>Genotype</th>
<th>Total milk yield (kg/cow)</th>
<th>Total milk solids yield (kg/cow)</th>
<th>Fat content (%)</th>
<th>Protein content (%)</th>
<th>Somatic cell count (cells/ml)</th>
<th>Average BW (kg/cow)</th>
<th>Average BCS</th>
<th>Milk solids/kg BW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HF(^1)</td>
<td>4,848</td>
<td>394</td>
<td>4.61</td>
<td>3.69</td>
<td>67.7</td>
<td>490</td>
<td>2.97</td>
<td>0.81</td>
</tr>
<tr>
<td>1</td>
<td>JEX</td>
<td>4,840</td>
<td>412</td>
<td>4.90</td>
<td>3.80</td>
<td>57.6</td>
<td>448</td>
<td>2.97</td>
<td>0.92</td>
</tr>
<tr>
<td>1</td>
<td>3WAY</td>
<td>4,779</td>
<td>396</td>
<td>4.67</td>
<td>3.79</td>
<td>62.7</td>
<td>455</td>
<td>2.97</td>
<td>0.87</td>
</tr>
<tr>
<td>2</td>
<td>HF</td>
<td>5,889</td>
<td>472</td>
<td>4.49</td>
<td>3.72</td>
<td>37.8</td>
<td>520</td>
<td>2.88</td>
<td>0.91</td>
</tr>
<tr>
<td>2</td>
<td>JEX</td>
<td>5,509</td>
<td>470</td>
<td>4.81</td>
<td>3.88</td>
<td>39.1</td>
<td>477</td>
<td>2.90</td>
<td>0.99</td>
</tr>
<tr>
<td>2</td>
<td>3WAY</td>
<td>5,497</td>
<td>463</td>
<td>4.73</td>
<td>3.89</td>
<td>29.2</td>
<td>499</td>
<td>2.96</td>
<td>0.93</td>
</tr>
<tr>
<td>3</td>
<td>HF</td>
<td>6,418</td>
<td>513</td>
<td>4.47</td>
<td>3.74</td>
<td>44.3</td>
<td>581</td>
<td>2.94</td>
<td>0.88</td>
</tr>
<tr>
<td>3</td>
<td>JEX</td>
<td>6,079</td>
<td>525</td>
<td>4.88</td>
<td>3.92</td>
<td>42.6</td>
<td>509</td>
<td>2.95</td>
<td>1.03</td>
</tr>
<tr>
<td>3</td>
<td>3WAY</td>
<td>5,819</td>
<td>501</td>
<td>4.87</td>
<td>3.95</td>
<td>38.4</td>
<td>542</td>
<td>3.05</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td>S.E.</td>
<td>74.6</td>
<td>5.5</td>
<td>0.060</td>
<td>0.027</td>
<td>6.38</td>
<td>5.8</td>
<td>0.019</td>
<td>0.013</td>
</tr>
</tbody>
</table>

\(^1\)HF = Holstein Friesian, JEX = Jersey × Holstein Friesian, 3WAY = Norwegian Red × Jersey × Holstein Friesian
5.5 Discussion

The use of crossbreeding in spring-calving systems has been limited in Ireland with only 5.2% of herds reported as crossbred in 2014 (DAFM, 2014). The trend for crossbred cows has been influenced by expanding herds and larger herd sizes, with a demand for ‘easy care’ or robust animals that suit reduced labour input systems and in particular pasture-based systems (Sørensen, 2007; Veerkamp et al., 2013). In the current study, the performance of all three genotypes was excellent, particularly in terms of reproductive performance, which was well above national average statistics for Ireland. However, the lack of an effect of genotype on reproductive performance is somewhat surprising as previous research has shown crossbred cows to have superior reproductive performance to HF (Prendiville et al., 2011a; Vance et al., 2013) and may be due to greater emphasis on functional traits and the development and use of the EBI (O’Sullivan et al., 2018; O’Sullivan et al., 2019a).

5.5.1 Milk production

The sward performance results (Table 5.3) confirm that all animals were provided with high quality herbage and therefore the expression of performance differences between cow genotypes should not have been influenced by herbage allowance or nutritive value. Total milk yield differences between genotypes (HF had 4.2% and 6.2% higher milk yield compared with JEX and 3WAY) are in agreement with multiple previous studies comparing HF to JEX cows (Prendiville et al., 2010; Vance et al., 2012; Coffey et al., 2017). This is due to the higher genetic merit for milk yield (i.e. milk kg; Table 5.2) for HF compared to JEX and 3WAY. However, MS production of HF and JEX cows in this thesis was similar which is in agreement with Vance et al. (2012) but in contrast with a number of studies that reported increased MS yield for JEX cows (Prendiville et al., 2011a; Coffey et al., 2016; Coffey et al., 2017). Milk solids yield per cow was similar due to the significantly higher fat and protein content of JEX milk compared with HF milk (White et al., 2001). Jersey × Holstein-Friesian had greater MS than 3WAY due to the numerically higher total milk yield and fat content of JEX cows. There are limited studies that compare 3WAY crosses, as used in this study, with HF and JEX. Hazel at al. (2014) compared purebred Holsteins, Holstein × Montbéliarde and a 3-breed crossbred of Montbéliarde × Jersey × Holstein in confinement and limited pasture access feeding systems and found no significant difference in total MS among all three breeds. However, in the confinement system the purebred Holsteins had greater MS production than the Montbéliarde × Jersey × Holstein,
perhaps indicating a greater suitability of Holsteins to confinement systems and of crossbreeds to pasture-based systems. Ferris et al. (2018) compared the production of purebred Holsteins with Swedish Red × Jersey × Holstein cows on low and medium input pasture-based systems. They found that purebred Holsteins had significantly higher total milk yields compared to the crossbreds but similar total MS yields. The results of the current study corroborate previous research in demonstrating the ability of HF animals crossed with Jersey and Norwegian Red to produce similar or increased MS to purebred HF from a lower milk volume in pasture-based production systems.

Crossbred animals can offer benefits in terms of milk production efficiency with JEX and 3WAY producing 0.98 and 0.91 kg MS/kg BW over the entire lactation, which is a 12.6% and 4.6% increase compared to HF (0.87 kg MS/kg BW). The 12.6% increase in MS/kg BW is similar to the 14% increase in MS/100 kg BW observed from JEX compared to HF cows by Coffey et al. (2017). The results confirm previous findings that the basis of the difference in production efficiency can be attributed to differences in BW, grazing behaviour (Prendiville et al., 2010; Vance et al., 2012) and gastrointestinal tract weight (Beecher et al., 2014) specifically associated with the Jersey breed. The intake capacity of Jersey animals is greater than other breeds in relation to total BW (Mackle et al., 1996). Prendiville et al. (2009) reported greater DMI/100 kg BW for F1 JEX compared to HF (3.63 vs. 3.39 kg/100 kg BW) which impacts production efficiencies in terms of BW in favour of Jersey and Jersey crossbred animals (Heins et al., 2008a). It is notable that the gains in efficiency were not as great for the 3WAY as they were for the JEX due to their higher BW and reduced MS. Further investigation of the production efficiencies in terms of BW, maintenance and DMI is required as few, if any studies have investigated these efficiencies for 3WAY cows.

The observation that parity 2 and 3+ cows produced 16.9% and 26.6% greater milk yield than parity 1 cows is in agreement with Berry (2015) who reported similar differences of 16% to 19% and 28% to 31%. These differences can be attributed to the greater peak in milk production associated with higher parity animals (Horan et al., 2005a). The interaction between parity and genotype for milk yield is due to the similar milk yield of all genotypes in parity 1 (range in milk yield for parity 1 animals was 69 kg/cow) whereas there were significant differences in milk yield amongst genotypes for parity 2 and 3+ animals (range in milk yield for parity 2 and 3+
animals was 392 and 599 kg/cow, respectively). Total MS yield increased as parity increased and total MS yield was significantly higher in parity 1 for JEX cows compared to HF and 3WAY. However, in agreement with a number of studies there was no interaction between genotype and parity for MS yield (Vance et al., 2012; Hazel et al., 2014). The parity by genotype interaction for milk yield per cow could be important as improved performance from parity 1 onwards can impact the profitability of an animal over their lifetime which may also have potential implications for future genetic evaluations. However, it should be acknowledged that the results observed are from a single study, with limited cow numbers so further investigation as to the validity of the parity by genotype interaction is required.

5.5.2 Reproductive performance

In spring-calving, pasture-based systems, a herd’s reproductive performance is critical as the basis of these systems is to calve cows in a short time-frame in spring, to match grass production with herd demand and maximise milk production from pasture (Shalloo et al., 2014). Poor reproductive performance in pasture-based systems has been linked to the early lactation weight loss which occurs due to cows’ mobilising body fat reserves to produce high milk yields (Beever et al., 2001; Buckley et al., 2003; Roche et al., 2007). It is therefore an important observation of the current study that the reproductive performance of all three genotypes was excellent, with similar results observed for key performance indicators of spring calving pasture-based herds, such as six-week pregnancy rate and overall pregnancy rate (on average 86.3% and 94.3% in this study, respectively). It should be noted however that JEX cows had a significantly earlier average mean calving date (2nd February) compared to HF and 3WAY (6th February and 7th February, respectively), likely due to their numerically higher pregnancy rate to first service. In this study the trends in BW and BCS loss in early lactation were similar for all three genotypes although 3WAY had a higher BCS than HF and JEX throughout lactation, as illustrated in Figure 5.3 and 5.4. All three genotypes outperformed national average reproduction figures for Ireland (national average six-week pregnancy rate = 64%; ICBF, 2019a) indicating excellent herd reproductive management.

Numerous studies have reported F1 JEX cows to have superior reproductive performance in seasonal, pasture-based systems compared to HF cows. Vance et al. (2013) and Prendiville et al. (2011a) reported higher submission rates, pregnancy rates to first and second service, six-week
pregnancy rate and total pregnancy rate in F1 JEX cows compared to HF cows across different seasonal pasture-based systems. Although the current results are in contrast with these previous studies, they corroborate more recent research that has shown improvements in the reproductive performance of HF in Ireland (O’Sullivan et al., 2018; ICBFa, 2019). Coffey et al. (2016) compared the reproductive performance of Holstein, Friesian and Jersey crossbred cows in spring-calving commercial dairy farms in Ireland, and found an average submission rate of 74% and a six-week pregnancy rate of 66% from 2008 to 2012, with no consistent genotype effect noted, although calving interval and age at first calving was significantly lower for crossbred animals compared to both parental averages. Leane (2016) reported no significant differences between HF and JEX cows for submission rate, six-week pregnancy rate or overall pregnancy rate across a number of pasture-based grazing treatments. There are very limited studies evaluating the effect of three-way rotational crossing on reproductive performance and none with the combination of breeds used in this study. Hazel et al. (2014) reported a significant difference between purebred Holsteins and Montbéliarde x Jersey x Holstein for pregnancy rate to first service, with the latter having a 23% higher rate along with having 43 fewer days open. Norwegian Red was chosen as the third breed in the current study due to the findings of Walsh et al. (2008) who concluded that of the three alternative breeds evaluated (Montbéliarde, Normande and Norwegian Red), the Norwegian Red was most suited to seasonal pasture-based milk production systems. Although the Norwegian Red produced slightly less milk (solids corrected) compared with HF, the breed displayed many favourable traits, namely, superior reproductive efficiency, superior udder health, and a moderate size. Ferris et al. (2018) reported, over one lactation, that Holstein cows had greater ovarian dysfunction than Swedish Red x Jersey x Holstein crossbreds however, overall reproductive performance was not reported.

As discussed previously, the reproductive performance of all three genotypes was excellent however, the lack of an effect of genotype on reproductive performance is somewhat surprising considering the contrasting breeds involved, the difference in EBI amongst genotypes (EBI was higher for both crossbred genotypes compared to HF; Table 5.2) and the anticipated effect of heterosis from crossbred cows. The HF cows in this thesis study performed extremely well and above national average statistics for Ireland’s predominantly HF herd (ICBF 2019a) despite the fact that the HF cows in this study had a similar average EBI of €115 (€42 fertility sub-index), compared to the national average in 2018 of €96 (€38 fertility sub-index; ICBF, 2019(b)). The lack of an effect of genotype on reproductive performance may be attributed to excellent
reproductive management (the same technician was in charge of reproductive management of the herd for the duration of the experiment), the early mean calving date of the herd, the relatively high average mean BCS of the HF within this study and also the long term gains in genetic merit for reproductive and functional traits since the introduction of the EBI in 2000 (Berry et al., 2005; O’Sullivan et al., 2018). It should also be noted that although HF and JEX had lower BCS than 3WAY, their mean BCS during lactation (2.94) is similar to that of the Elite cows in the Teagasc “Next Generation Herd” (2.91; O’Sullivan et al., 2019b). It has been well documented that genetic selection for fertility and health traits in lactating dairy cows results in improved fertility phenotypes (Cummins et al., 2012; Moore et al., 2014; O’Sullivan et al., 2018).

5.5.3 BW, BCS and functional traits

In this study, crossbreeding with Jersey and subsequently with Norwegian Red, resulted in lighter cows compared to HF, and in the case of the 3WAY, cows with higher BCS. Auldist et al. (2007) found BCS in early lactation to be slightly higher for Jersey × Holstein cows than for Holstein cows, but the changes in BCS between calving and the start of breeding were similar between breed groups. They also reported Holstein cows to be 40 kg heavier than Jersey × Holstein cows. Similarly, Heins et al. (2008a) carried out a study using housed, first lactation cows where JEX cows had significantly lower BW (- 33 kg) and significantly higher BCS (2.90 vs. 2.76) than pure Holstein cows. This is in contrast to the current results where there was no significant difference in BCS between HF and JEX cows but the HF cows were 52 kg heavier than JEX. The 3WAY crossbred used by Ferris et al. (2018) had significantly higher BCS compared with HF, which is supported by the results of this thesis. With regards to the 3WAY crossbreds, there is no debate about the positive effect on BCS that breeds such as Norwegian Red, Swedish Red, Montbéliarde, Normande, etc. contribute to a F1 cross or backcross due to the breeding programmes of these breeds selecting for improved reproductive and functional traits (Walsh et al., 2008; Shonka-Martin et al., 2018).

There was no effect of genotype on the recorded functional traits (calving difficulty, lameness incidence, mastitis incidence or somatic cell count), which is in contrast with previous reports that crossbreeding would lead to a more robust, easy care cow (Buckley et al., 2014). Calving difficulty or dystocia has been defined in the Irish context as a calving event where the cow
needs mechanical intervention or veterinary assistance. A review undertaken in 2008 reported a prevalence of dystocia at 4.1% in Irish dairy herds with dams being primarily HF, but in Norway where the primary dam is Norwegian Red, a calving difficulty of just 1.5% has been reported (Mee, 2008). There was no difference in calving difficulty observed between the three genotypes in this study and all sires chosen for breeding had similar figures for expected calving difficulty. However, half of all HF cows in this study were bred to Jersey sires, which have lower calving difficulty than other breeds, and this may have benefited the uterine health of HF in the subsequent breeding season.

Lameness is an important health trait in dairy cows that can have a negative impact on animal production and economic performance (Green et al., 2002). While the JEX and 3WAY cows had a numerically lower incidence of lameness in this study compared to HF, it was not significantly different. Previous studies have found similar results with differences in lameness between purebred HF and crossbred cows being insignificant (Bjelland et al., 2011; Vance et al., 2012, Ferris et al., 2018). There are also limited studies on the prevalence of lameness in pasture-based systems, however a recent study undertaken on pasture-based dairy herds in Australia concluded there was an average prevalence of lameness of 18.9% (Ranjbar et al., 2016), which aligns well with the lameness incidences reported in this study. Higher parity animals in this study had increased incidences of lameness, which is in agreement with Pryce et al. (1999) who reported that incidence of disease increased as parity increased. Booth et al. (2004) also predicted a four times higher risk of lameness in cows with parity 3+ compared to parity 1.

Genotype had no effect on the recorded incidences of mastitis in this study, with an average prevalence of 6.5% across the herd. This is consistent with previous studies where there was no significant difference in prevalence of mastitis between HF and crossbred cows (Prendiville et al., 2010; Bjelland et al., 2011). In contrast to the above studies, Ferris et al. (2018) found Holstein cows to have significantly higher incidences of mastitis compared to a 3WAY breed of Swedish Red × Jersey × Holstein (26% vs. 6%, respectively), but found the 3WAY breed to have a significantly higher SCC compared to the Holstein cows. Similarly, Vance et al. (2012) found HF cows to have significantly higher cases of mastitis compared to Jersey × HF cows (29% vs. 16%, respectively). However, Vance et al. (2012) reported no difference in SCC between the two breeds, similar to Prendiville et al. (2010) who found no difference in SCC
between HF, Jersey or JEX cows. This is in agreement with the modelled benefits of heterosis on SCC, which found small insignificant differences between purebred and crossbred cows (VanRaden and Sanders, 2003). The lack of a genotype effect is somewhat surprising, particularly for the 3WAY, as functional and health traits have been selected for in the Norwegian Red breeding programme for the last number of decades (Walsh et al., 2008). The EBI has a relative emphasis of 4% on health traits and the results suggest that this has been sufficient to provide high EBI genetic animals, regardless of genotype, that are suitable for pasture-based production systems.

The greater mean lactation SCC for parity 1 compared with parity 2 and 3+ animals is in contrast with previous research which showed that lactation average SCC increased as parity increased (McCarthy et al., 2007; Walsh et al., 2007), although parity did not affect the incidence of mastitis. It is unclear why parity 1 animals had a greater mean lactation SCC than older parity animals however, the overall mean SCC among parities was below the 100,000 cells/ml that would indicate subclinical infection (Ruegg and Pantoja, 2013). Therefore it is unlikely that differences in mean SCC among parities had an effect on milk production.

5.6 Conclusion

Holstein-Friesian cows in this study had higher milk yields compared to JEX and 3WAY however; all three genotypes had similar MS production. High levels of reproductive performance were achieved for all three genotypes. Where commercial HF dairy herds are achieving similar levels of performance, particularly in terms of reproductive performance, to the HF in this study, the use of crossbreeding is unlikely to lead to significant improvements. However, the average herd in Ireland is likely to benefit from crossbreeding, to a greater extent than that reported in this study. There was evidence of crossbreeding benefits in terms of the efficiency of MS production per kg BW. The combination of similar MS production, reproductive performance and health traits made all three genotypes suitable for spring-calving, pasture-based milk production systems.
Chapter 6

Effect of sward type and cow genotype on dry-matter intake and production efficiencies of spring-calving grazing dairy cows

6.1 Summary

Achieving high DMI from grazed forage is vital in pasture-based systems and can be affected by numerous factors. The following chapter will explore the impact of sward type (PRG ploidy and white clover inclusion), cow genotype and parity on DMI in pasture-based systems. Four separate grazing treatments were evaluated for DMI; tetraploid PRG-only, diploid PRG-only, tetraploid PRG with white clover and diploid PRG with white clover. Three genotypes were also evaluated for DMI; Holstein Friesian (HF), Jersey x HF (JEX) and JEX x Norwegian Red (3WAY) along with their parity results. Individual DMI was estimated eight times during the study, three times in 2015, two times in 2016 and three times in 2017, using the n-alkane technique. Each DMI measurement period corresponded to 64, 110 and 189 days in milk and correlates to spring, summer and autumn. Measures of milk production efficiency calculated were: total DMI/100 kg BW, milk solids (kg fat + protein; MS)/ 100 kg BW, unité fourragère lait (UFL) available for standard (4.0% fat and 3.1% protein content) milk production after accounting for maintenance and gestation, and UFL required to produce 1 kg of milk and MS (g) per UFL intake before and after accounting for maintenance. Perennial ryegrass ploidy had no impact on DMI, however, significant increases in DMI was observed from cows grazing PRG-white clover swards compared to PRG-only, which ultimately increased milk and MS yields. Cows grazing PRG-white clover swards were also more efficient for TDMI/100 kg BW, SCM/100 kg BW and Milk solids/100 kg of BW compared to PRG-only, due to their similar BW but higher milk and MS yield. Dry-matter intakes differed significantly between genotypes which consequently affected production efficiencies with regards to cow BW and MS production, with JEX cows being the most efficient for TDMI/100 kg BW, SCM/100 kg BW and Milk solids/100 kg of BW. Dry-matter intakes also differed significantly between parities with the higher parity cows having higher intakes, higher energy balance and subsequently higher milk and MS yield.
6.2 Introduction

The conversion of grazed forage into highly nutritious dairy products is synonymous with temperate grazing regions of the world. This low-cost system has resulted in Ireland having a specific advantage due to its high capacity for producing milk from grazed forage (Dillon et al., 2008). Within pasture-based grazing systems the efficient production of milk is heavily dependent on variable costs, of which feed can make up to 80% (Connolly et al., 2010; Finneran et al., 2010). To maximise profitability in these systems, costs can be reduced by increasing pasture utilisation and reducing the proportion of bought in supplement (Ramsbottom et al., 2015; Macdonald et al., 2017; Hanrahan et al., 2018). Therefore, achieving a high DMI from grazed forage is critical to ensure high animal performance which can be heavily influenced by both sward type and animal genotype (Gowen et al., 2003; Berry et al., 2007; Coleman et al., 2010).

Sward type can affect pasture DMI as certain forages are more palatable and digestible than others. Balocchi and Lopez (2010) showed cows grazing diploid and tetraploid PRG swards had a preference for the tetraploid swards, illustrated by a higher utilisation rate and lower post-grazing residual. This may infer a relationship between grazing preference and DMI, as cows have also been shown to have greater pasture DMI when grazing tetraploid swards compared to diploid swards (Latinga and Groot, 1996; Gowen et al., 2003). White clover is an important legume in temperate grazing regions for a number of reasons, one of which is that white clover has been shown to be grazed preferentially over PRG and increases DMI in mixed swards (Ribeiro Filho et al., 2003; Rutter et al., 2004; Egan et al., 2018). This preference has been linked to a faster rumen passage rate of white clover compared to PRG due to its lower NDF and ADF content (Minson, 1990; Egan et al., 2018).

Cow genotype plays a large role in the utilisation of pastures with the ideal cow calving to match pasture supply in spring, having a high intake of grazed pasture throughout lactation and subsequently converting this pasture efficiently into high quality milk (Berry et al., 2015). Crossbreeding traditional Holstein-Friesian (HF) with Jersey has become popular in some temperate grazing regions due to the benefits of heterosis leading to improved milk composition and reproductive performance of Jersey x HF (JEX) crossbred cows (Prendiville et al., 2011a; Vance et al., 2013). The suitability of JEX cows for pasture-based systems is due to their lower
BW and greater gastrointestinal tract size relative to their BW (Prendiville et al., 2009; Beecher et al., 2014). This leads to increased DMI per unit BW and greater production efficiencies for JEX cows compared to HF and make JEX cows uniquely suited for intensive grazing systems (Prendiville et al., 2009; Vance et al., 2012; Coffey et al., 2017). Lopez-Villalobos et al. (2000) hypothesised that a 3-way rotational crossing system could increase profitability for pasture-based systems in New Zealand. However, there is a paucity of information regarding the effect of introducing a third genotype into a rotational crossing system on DMI and subsequent production efficiencies.

The objective of this chapter study was to investigate the effect of sward type (PRG ploidy, with and without white clover), cow genotype and parity on DMI and animal production efficiencies.

6.3 Materials and Methods

6.3.1 Experimental design and treatments

The experiment was a randomised block design with a 2 x 2 factorial arrangement of treatments creating four grazing treatments, a tetraploid PRG-only sward (TGO), a diploid PRG-only sward (DGO), a tetraploid PRG sward with white clover (TWC) and a diploid PRG sward with white clover (DWC). Every year each grazing treatment was grazed by 30 cows (ten of each genotype; HF, JEX and 3WAY). Further detail of the experimental design and grazing treatments can be found in Chapter 3.

6.3.2 Herbage dry-matter intake and production efficiencies

Individual DMI was estimated eight times during the study, three times in 2015, two times in 2016 and three times in 2017, using the n-alkane technique (Mayes et al., 1986) as modified by Dillon and Stakelum (1989). During each DMI measurement period cows were on average 64, 110 and 189 days in milk, respectively corresponding to spring, summer and autumn each year. All cows were dosed twice daily, after milking, for 12 consecutive days with a paper bullet containing 760 mg of C32-alkane (n-dotriacontane). From days 8-12 of dosing, faecal samples were collected from each cow twice daily before morning and evening milking, either in the paddock the hour before milking by observing the cows and collecting the faecal sample when cows voided or by rectal grab sampling after milking. Faecal samples were stored at -18 °C until
the end of the collection period. Faecal samples from each cow were thawed and bulked together, dried at 60 °C for 48 hours, milled through a 1 mm screen and analysed for alkane concentration. Herbage samples of approximately 15 individual grass snips were manually collected using Gardena hand shears mimicking the grazing defoliation pattern observed on previously grazed swards, before each grazing event on days 7-11. The herbage samples were stored at -18°C. Frozen herbage samples were bowl-chopped freeze-dried at -50°C for 72 hours, milled through a 1 mm screen and analysed for alkane concentration. The ratio of dosed C32-alkane to herbage C33 (tritricontane) was used to estimate DMI using the equation described by Mayes et al. (1986). Measures of milk production efficiency were calculated based on the net energy system (Faverdin et al., 2011), where 1 unité fourragère lait (UFL) of energy is defined as the net energy content of 1 kg of standard barley for milk production, equivalent to 1,700 kcal. The measures of milk production efficiency were total DMI per 100 kg of BW, MS (kg) per 100 kg of BW, UFL available for standard (4.0% fat and 3.1% protein content) milk production after accounting for maintenance and gestation, and UFL required to produce 1 kg of milk and MS (g) per UFL intake before and after accounting for maintenance.

6.3.3 Statistical analysis: Dry-matter intake and production efficiencies

Total and pasture DMI, energy intake, energy balance, total DMI per 100 kg BW, SCM per 100 kg BW, MS per 100 kg BW and MS per total DMI were analysed using PROC MIXED (SAS, SAS Institute Inc., Cary, NC), taking into account the effects of year, measurement period, ploidy, white clover treatment, genotype, parity, and the associated interactions such as ploidy x white clover treatment, measurement period x white clover treatment and genotype x parity were included in the model. Individual cow was the experimental unit and measurement period (spring, summer or autumn) was the repeated measure.

6.4 Results

6.4.1 Sward measurements

Pre-grazing herbage mass differed between grazing treatments during the intake measurement periods with the two ploidies differing significantly ($P = 0.01$; Table 6.1). Diploid swards had an average PrGHM of 1,784 kg DM/ha, while tetraploid swards were lower at 1,527 kg DM/ha. White clover inclusion had no impact on PrGHM and there was no interaction between ploidy.
and white clover inclusion. Similarly, PrGSH was significantly different between ploidy ($P = 0.019$), with tetraploid swards having a higher PrGSH, while there was no response to white clover inclusion. Post-grazing sward height differed between ploidies and also when white clover was included. Tetraploid swards were grazed lower than diploid swards ($P < 0.001$), and PRG-white clover swards (TWC and DWC) were grazed lower than PRG-only swards (TGO and DGO; $P = 0.015$). Herbage allowance differed between ploidy but was not altered by white clover inclusion, with diploid swards having a higher herbage allowance ($P = 0.048$). White clover content was not affected by ploidy but differed significantly between seasons, being lowest in spring (8.9%), increasing in summer (14.2%) and peaking in autumn (23.7%).
Table 6.1 Comparison of perennial ryegrass ploidy and of white clover inclusion on grazing sward characteristics

<table>
<thead>
<tr>
<th></th>
<th>Treatment</th>
<th>P-value</th>
<th>P-value</th>
<th>P-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tetraploid PRG-only</td>
<td>Diploid PRG-only</td>
<td>Tetraploid + white clover</td>
<td>Diploid + white clover</td>
<td>SE</td>
</tr>
<tr>
<td>Pre-grazing herbage mass (kg DM/ha)</td>
<td>1,568</td>
<td>1,799</td>
<td>1,485</td>
<td>1,769</td>
<td>100.0</td>
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<tr>
<td>Spring</td>
<td>1,669</td>
<td>1,784</td>
<td>1,432</td>
<td>1,921</td>
<td>165.3</td>
</tr>
<tr>
<td>Summer</td>
<td>1,441</td>
<td>1,907</td>
<td>1,328</td>
<td>1,616</td>
<td>194.1</td>
</tr>
<tr>
<td>Autumn</td>
<td>1,594</td>
<td>1,706</td>
<td>1,694</td>
<td>1,769</td>
<td>154.6</td>
</tr>
<tr>
<td>Pre-grazing sward height (cm)</td>
<td>8.51</td>
<td>8.40</td>
<td>9.10</td>
<td>9.03</td>
<td>0.258</td>
</tr>
<tr>
<td>Spring</td>
<td>7.97</td>
<td>8.40</td>
<td>7.89</td>
<td>9.01</td>
<td>0.423</td>
</tr>
<tr>
<td>Summer</td>
<td>8.38</td>
<td>9.72</td>
<td>7.39</td>
<td>8.33</td>
<td>0.505</td>
</tr>
<tr>
<td>Autumn</td>
<td>9.18</td>
<td>9.18</td>
<td>9.93</td>
<td>9.73</td>
<td>0.396</td>
</tr>
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<tr>
<td>Spring</td>
<td>3.63</td>
<td>3.93</td>
<td>3.36</td>
<td>3.95</td>
<td>0.170</td>
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<tr>
<td>Summer</td>
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<td>4.65</td>
<td>3.73</td>
<td>4.08</td>
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</tr>
<tr>
<td>Autumn</td>
<td>4.12</td>
<td>4.55</td>
<td>4.04</td>
<td>4.07</td>
<td>0.159</td>
</tr>
<tr>
<td>Herbage allowance (kg DM/cow)</td>
<td>15.0</td>
<td>16.0</td>
<td>14.0</td>
<td>16.4</td>
<td>0.87</td>
</tr>
<tr>
<td>Spring</td>
<td>16.3</td>
<td>16.8</td>
<td>13.3</td>
<td>16.2</td>
<td>1.43</td>
</tr>
<tr>
<td>Summer</td>
<td>11.8</td>
<td>14.3</td>
<td>12.1</td>
<td>15.6</td>
<td>1.72</td>
</tr>
<tr>
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<td>17.1</td>
<td>16.7</td>
<td>17.6</td>
<td>1.33</td>
</tr>
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<td>White clover %</td>
<td>-</td>
<td>-</td>
<td>17.2</td>
<td>14.0</td>
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</tr>
<tr>
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<td>-</td>
<td>-</td>
<td>9.4</td>
<td>8.5</td>
<td>2.93</td>
</tr>
<tr>
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<td>-</td>
<td>-</td>
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<td>13.7</td>
<td>3.61</td>
</tr>
<tr>
<td>Autumn</td>
<td>-</td>
<td>-</td>
<td>27.6</td>
<td>19.8</td>
<td>2.680</td>
</tr>
</tbody>
</table>
Sward nutritive values are shown in Table 6.2. Neither ploidy nor white clover inclusion affected OMD content; however, OMD declined from spring to summer and subsequently from summer to autumn, regardless of sward type. Crude protein content did not differ between ploidy but was significantly higher in white clover swards ($P < 0.001$). There was a seasonal variation in CP content with the highest values observed in spring, intermediate in summer and lowest in autumn. NDF content was similar between tetraploid and diploid swards but was significantly lower when white clover was present ($P = 0.038$). Differences were also observed throughout the year with NDF content highest in summer for all swards types. ADF content did not differ with ploidy or white clover inclusion and was relatively similar between seasons. Ash content did not differ between ploidy but was significantly higher in white clover swards ($P < 0.001$).
Table 6.2 Comparison of perennial ryegrass ploidy and white clover inclusion on grazing sward nutritive values

<table>
<thead>
<tr>
<th>Treatment</th>
<th>OMD (g/kg DM)</th>
<th>Crude protein (g/kg DM)</th>
<th>NDF (g/kg DM)</th>
<th>ADF (g/kg DM)</th>
<th>Ash (g/kg DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tetraploid PRG-only</td>
<td>Diploid PRG-only</td>
<td>Tetraploid + white clover</td>
<td>Diploid + white clover</td>
<td>S.E.</td>
</tr>
<tr>
<td>OMD (g/kg DM)</td>
<td>809</td>
<td>806</td>
<td>808</td>
<td>806</td>
<td>0.3</td>
</tr>
<tr>
<td>Spring</td>
<td>818</td>
<td>818</td>
<td>816</td>
<td>815</td>
<td>0.4</td>
</tr>
<tr>
<td>Summer</td>
<td>808</td>
<td>806</td>
<td>811</td>
<td>806</td>
<td>0.4</td>
</tr>
<tr>
<td>Autumn</td>
<td>800</td>
<td>793</td>
<td>797</td>
<td>797</td>
<td>0.5</td>
</tr>
<tr>
<td>Crude protein (g/kg DM)</td>
<td>183</td>
<td>181</td>
<td>210</td>
<td>213</td>
<td>4.0</td>
</tr>
<tr>
<td>Spring</td>
<td>198</td>
<td>196</td>
<td>219</td>
<td>214</td>
<td>6.6</td>
</tr>
<tr>
<td>Summer</td>
<td>183</td>
<td>181</td>
<td>213</td>
<td>217</td>
<td>6.6</td>
</tr>
<tr>
<td>Autumn</td>
<td>167</td>
<td>167</td>
<td>198</td>
<td>209</td>
<td>8.6</td>
</tr>
<tr>
<td>NDF (g/kg DM)</td>
<td>388</td>
<td>402</td>
<td>369</td>
<td>366</td>
<td>11.9</td>
</tr>
<tr>
<td>Spring</td>
<td>358</td>
<td>361</td>
<td>342</td>
<td>364</td>
<td>18.6</td>
</tr>
<tr>
<td>Summer</td>
<td>419</td>
<td>418</td>
<td>388</td>
<td>383</td>
<td>18.6</td>
</tr>
<tr>
<td>Autumn</td>
<td>386</td>
<td>427</td>
<td>377</td>
<td>351</td>
<td>24.2</td>
</tr>
<tr>
<td>ADF (g/kg DM)</td>
<td>217</td>
<td>221</td>
<td>220</td>
<td>217</td>
<td>4.8</td>
</tr>
<tr>
<td>Spring</td>
<td>194</td>
<td>195</td>
<td>201</td>
<td>198</td>
<td>7.5</td>
</tr>
<tr>
<td>Summer</td>
<td>228</td>
<td>234</td>
<td>227</td>
<td>229</td>
<td>7.5</td>
</tr>
<tr>
<td>Autumn</td>
<td>231</td>
<td>234</td>
<td>231</td>
<td>225</td>
<td>9.8</td>
</tr>
<tr>
<td>Ash (g/kg DM)</td>
<td>78.3</td>
<td>77.2</td>
<td>81.8</td>
<td>83.2</td>
<td>0.07</td>
</tr>
<tr>
<td>Spring</td>
<td>73.2</td>
<td>71.1</td>
<td>74.8</td>
<td>74.1</td>
<td>0.11</td>
</tr>
<tr>
<td>Summer</td>
<td>79.9</td>
<td>80.2</td>
<td>83.3</td>
<td>89.9</td>
<td>0.13</td>
</tr>
<tr>
<td>Autumn</td>
<td>81.6</td>
<td>80.2</td>
<td>87.2</td>
<td>85.6</td>
<td>0.11</td>
</tr>
</tbody>
</table>
6.4.2 Animal performance

Cows grazing PRG-white clover swards had higher daily milk (23.1 vs. 21.7 kg/cow) and MS (1.85 vs. 1.75 kg/cow) yield compared to PRG-only swards during the intake measurement periods, with this effect evident in each season ($P < 0.001$; Table 6.3). Tetraploid swards tended ($P = 0.059$) to have higher daily milk yield than diploid swards (22.6 vs. 22.2 kg/cow, respectively), with the greatest effect being observed in autumn from cows grazing tetraploid swards. Daily MS yield was significantly affected by ploidy ($P = 0.016$), with higher yields observed from cows grazing tetraploid swards compared to diploid swards (1.82 vs. 1.78 kg/cow, respectively). Milk fat content was not affected by ploidy or white clover inclusion. Milk protein content was lower for cows grazing PRG-white clover swards ($P = 0.047$), but did not differ between ploidy (Table 6.3).

Milk yield was significantly affected by genotype ($P < 0.001$) with HF having the highest daily yield (23.2 kg/cow), followed by JEX (22.0 kg/cow) and 3WAY (21.9 kg/cow) which were similar (Table 6.4). However, milk fat content was higher for JEX (4.54%) and 3WAY (4.34%) cows compared to HF cows (4.22%). Similarly milk protein content was higher for JEX (3.80%) and 3WAY (3.76%) cows compared to HF cows (3.62%). This resulted in similar daily MS yields between all breeds ($P = 0.13$). Milk and MS yield decreased from spring to summer and summer to autumn, while milk fat and protein content increased.

There was a significant effect of parity on milk and MS yield, which increased linearly with parity (Table 6.5). Parity 1 had the lowest daily milk (19.3 kg/cow) and MS yield (1.54 kg/cow), parity 2 cows yielded significantly higher milk (22.9 kg/cow) and MS yield (1.84 kg/cow), and parity 3 + had the highest milk (25.0 kg/cow) and MS yield (2.02 kg/cow). There was no effect of parity on milk fat content, but milk protein content was lowest ($P = 0.014$) in parity 1 cows (3.68%) and similar between parity 2 and 3+ animals (3.76% and 3.74%, respectively).
Table 6.3 Comparison of perennial ryegrass ploidy and white clover inclusion on milk yield, milk solids yield and milk composition

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Treatment</th>
<th>Treatment</th>
<th>Treatment</th>
<th>SE</th>
<th>Ploidy</th>
<th>White</th>
<th>Ploidy * White</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily milk yield (kg/cow)</td>
<td>Tetraploid PRG-only</td>
<td>Diploid PRG-only</td>
<td>Tetraploid + white clover</td>
<td>Diploid + white clover</td>
<td>0.23</td>
<td>0.059</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Spring</td>
<td>25.0</td>
<td>24.8</td>
<td>26.3</td>
<td>25.6</td>
<td>0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>22.8</td>
<td>23.6</td>
<td>24.5</td>
<td>24.0</td>
<td>0.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>17.8</td>
<td>17.1</td>
<td>19.3</td>
<td>18.7</td>
<td>0.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk fat %</td>
<td>4.39</td>
<td>4.37</td>
<td>4.37</td>
<td>4.32</td>
<td>0.051</td>
<td>0.558</td>
<td>0.358</td>
</tr>
<tr>
<td>Spring</td>
<td>4.23</td>
<td>4.31</td>
<td>4.20</td>
<td>4.26</td>
<td>0.067</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>4.28</td>
<td>4.31</td>
<td>4.37</td>
<td>4.18</td>
<td>0.079</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>4.68</td>
<td>4.53</td>
<td>4.54</td>
<td>4.52</td>
<td>0.066</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk protein %</td>
<td>3.75</td>
<td>3.74</td>
<td>3.71</td>
<td>3.70</td>
<td>0.022</td>
<td>0.419</td>
<td>0.047</td>
</tr>
<tr>
<td>Spring</td>
<td>3.53</td>
<td>3.53</td>
<td>3.48</td>
<td>3.48</td>
<td>0.028</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>3.72</td>
<td>3.72</td>
<td>3.75</td>
<td>3.71</td>
<td>0.033</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>4.01</td>
<td>3.96</td>
<td>3.91</td>
<td>3.90</td>
<td>0.028</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily milk solids (kg/cow)</td>
<td>1.76</td>
<td>1.74</td>
<td>1.88</td>
<td>1.81</td>
<td>0.019</td>
<td>0.016</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Spring</td>
<td>1.93</td>
<td>1.93</td>
<td>2.01</td>
<td>1.96</td>
<td>0.026</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>1.82</td>
<td>1.84</td>
<td>2.00</td>
<td>1.89</td>
<td>0.031</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>1.53</td>
<td>1.45</td>
<td>1.63</td>
<td>1.57</td>
<td>0.025</td>
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<td></td>
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</table>
Table 6.4 Comparison of cow genotypes for milk yield, milk solids yield and milk composition

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Holstein-Friesian</th>
<th>Jersey x Holstein-Friesian</th>
<th>Norwegian Red x Jersey x Holstein-Friesian</th>
<th>SE</th>
<th>Genotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily milk yield (kg/cow)</td>
<td>23.2</td>
<td>22.0</td>
<td>21.9</td>
<td>0.25</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Spring</td>
<td>26.6</td>
<td>24.6</td>
<td>25.1</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>24.4</td>
<td>23.3</td>
<td>23.0</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>18.7</td>
<td>18.3</td>
<td>17.7</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>Milk fat %</td>
<td>4.22</td>
<td>4.54</td>
<td>4.34</td>
<td>0.055</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Spring</td>
<td>4.10</td>
<td>4.44</td>
<td>4.21</td>
<td>0.066</td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>4.13</td>
<td>4.47</td>
<td>4.25</td>
<td>0.074</td>
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</tr>
<tr>
<td>Autumn</td>
<td>4.43</td>
<td>4.72</td>
<td>4.55</td>
<td>0.065</td>
<td></td>
</tr>
<tr>
<td>Milk protein %</td>
<td>3.62</td>
<td>3.80</td>
<td>3.76</td>
<td>0.023</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Spring</td>
<td>3.38</td>
<td>3.59</td>
<td>3.54</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>3.61</td>
<td>3.81</td>
<td>3.75</td>
<td>0.031</td>
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</tr>
<tr>
<td>Autumn</td>
<td>3.85</td>
<td>3.98</td>
<td>4.00</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>Daily milk solids (kg/cow)</td>
<td>1.81</td>
<td>1.82</td>
<td>1.77</td>
<td>0.020</td>
<td>0.130</td>
</tr>
<tr>
<td>Spring</td>
<td>1.98</td>
<td>1.96</td>
<td>1.94</td>
<td>0.025</td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>1.89</td>
<td>1.92</td>
<td>1.86</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>1.55</td>
<td>1.59</td>
<td>1.51</td>
<td>0.024</td>
<td></td>
</tr>
</tbody>
</table>
Table 6.5 Comparison of cow parity on milk yield, milk solids yield and milk composition

<table>
<thead>
<tr>
<th></th>
<th>Parity 1</th>
<th>Parity 2</th>
<th>Parity 3+</th>
<th>SE</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Daily milk yield (kg/cow)</strong></td>
<td>19.3</td>
<td>22.9</td>
<td>25.0</td>
<td>0.21</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Spring</td>
<td>21.6</td>
<td>26.1</td>
<td>28.8</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>20.1</td>
<td>23.9</td>
<td>26.4</td>
<td>0.31</td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>16.1</td>
<td>18.8</td>
<td>20.4</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td><strong>Milk fat %</strong></td>
<td>4.35</td>
<td>4.35</td>
<td>4.40</td>
<td>0.046</td>
<td>0.589</td>
</tr>
<tr>
<td>Spring</td>
<td>4.29</td>
<td>4.21</td>
<td>4.27</td>
<td>0.061</td>
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</tr>
<tr>
<td>Summer</td>
<td>4.27</td>
<td>4.29</td>
<td>4.31</td>
<td>0.072</td>
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</tr>
<tr>
<td>Autumn</td>
<td>4.49</td>
<td>4.56</td>
<td>4.62</td>
<td>0.060</td>
<td></td>
</tr>
<tr>
<td><strong>Milk protein %</strong></td>
<td>3.68</td>
<td>3.76</td>
<td>3.74</td>
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<td>0.0140</td>
</tr>
<tr>
<td>Spring</td>
<td>3.49</td>
<td>3.53</td>
<td>3.51</td>
<td>0.026</td>
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</tr>
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<td>Summer</td>
<td>3.66</td>
<td>3.76</td>
<td>3.74</td>
<td>0.030</td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>3.89</td>
<td>3.97</td>
<td>3.96</td>
<td>0.025</td>
<td></td>
</tr>
<tr>
<td><strong>Daily milk solids (kg/cow)</strong></td>
<td>1.54</td>
<td>1.84</td>
<td>2.02</td>
<td>0.017</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Spring</td>
<td>1.67</td>
<td>2.02</td>
<td>2.18</td>
<td>0.023</td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>1.59</td>
<td>1.92</td>
<td>2.13</td>
<td>0.027</td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>1.34</td>
<td>1.60</td>
<td>1.74</td>
<td>0.023</td>
<td></td>
</tr>
</tbody>
</table>
6.4.3 Dry-matter intake

Ploidy had no effect on total DMI (TDMI) or Pasture DMI (PDMI). However, cow grazing PRG-white clover swards had significantly higher PDMI ($P = 0.002$) compared to PRG-only swards with an average increase in PMDI of + 0.5 kg (16.5 vs. 16.0 kg, respectively, Table 6.6). The effect of white clover varied over the season as there was no difference in TDMI between PRG-only and PRG-white clover swards in spring (17.0 vs. 16.8 kg DM/cow, respectively), whereas PRG-white clover swards had a greater TDMI in summer and autumn (17.4 and 17.3 kg DM/cow, respectively) compared to PRG-only swards (16.8 and 16.4 kg DM/cow, respectively).

Cows grazing tetraploid swards had a higher daily energy intake (DEI) compared to diploids (19.1 vs. 18.8 UFL/day, $P = 0.046$), and also when grazing PRG-white clover swards compared to PRG-only swards (19.2 vs. 18.7 UFL/day, $P = 0.012$). However, daily energy balance was not affected by ploidy or white clover presence, and daily energy balance increased throughout the year.

Total DMI and PDMI differed significantly between genotypes (Table 6.7), with HF having the highest PDMI (16.5 kg/cow), followed by JEX (16.2 kg/cow) and 3WAY (15.9 kg/cow). Consequently DEI approached significance ($P = 0.056$) between breeds, with HF the highest (19.2 UFL/day), followed by JEX (18.9 UFL/day) and 3WAY (18.8 UFL/day). However, this did not impact daily energy balance, as all genotypes were similar ($P = 0.77$) and again daily energy balance increased throughout the year for every genotype. Total DMI and PDMI increased linearly as parity increased ($P < 0.001$, Table 6.8), and this effect was seen for each parity throughout the year with intakes peaking in autumn. Parity 3+ had the highest PDMI (18.1 kg/cow), followed by parity 2 cows (16.7 kg/cow), with parity 1 having the lowest (13.8 kg/cow). Consequently DEI was significantly impacted by parity ($P < 0.001$), with older parity animals having higher energy intakes (19.5 and 21.1 UFL/day for parity 2 and 3 + respectively, vs. 16.2 UFL/day for parity 1 cows, respectively). Daily energy balance was also significantly different ($P < 0.001$) between parities with lower energy balances observed for parity 1 animals (1.89 UFL/day) compared to Parity 2 and 3 + (2.89 and 3.05 UFL/day, respectively). Daily energy balances increased throughout the year, with the highest values observed in autumn.

Further comparisons between the breeds for production efficiencies showed that TDMI was highest for HF, followed by JEX and 3WAY ($P = 0.042$, Table 6.9). Total DMI, SCM and MS per 100 kg BW were all significantly different between genotypes with JEX having the highest
efficiency for all three measurements. Bodyweight was also significantly different between genotypes with JEX being the lightest (470 kg), followed by 3WAY (485 kg) and HF (514 kg). Total DMI/100 kg BW was highest for JEX (3.63 kg), followed by 3WAY (3.45 kg) and HF (3.36 kg). Similarly, SCM and MS per 100 kg BW followed the same trend with SCM/100 kg BW highest for JEX (4.96 kg), followed by 3WAY (4.63 kg) and HF (4.51 kg) and MS/100 kg BW being highest with JEX (0.39 kg), followed by 3WAY (0.37 kg) and HF (0.35 kg).

None of the production efficiencies were affected by PRG ploidy, however, when white clover was present in the swards there was a significant increase in TDMI/100 kg BW, SCM/100 kg BW, MS/100 kg BW and MS/TDMI. Total DMI/100 kg BW was significantly higher on PRG-white clover swards compared to PRG-only (3.53 vs. 3.44 kg respectively). Similarly, for SCM/100 kg BW PRG-white clover swards were higher compared to PRG-only (4.83 vs. 4.58 kg, respectively) and for MS/100 kg BW (0.38 vs. 0.36 kg, respectively, Table 6.10).
### Table 6.6 Comparison of perennial ryegrass ploidy and white clover inclusion on total and pasture dry-matter intake, energy intake and energy balance

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Tetraploid</th>
<th>Diploid</th>
<th>Tetraploid + white clover</th>
<th>Diploid + white clover</th>
<th>SE</th>
<th>Ploidy</th>
<th>White clover</th>
<th>Ploidy * white clover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasture dry-matter intake (kg)</td>
<td>16.1</td>
<td>15.8</td>
<td>16.5</td>
<td>16.4</td>
<td>0.15</td>
<td>0.251</td>
<td>0.003</td>
<td>0.538</td>
</tr>
<tr>
<td>Spring</td>
<td>15.9</td>
<td>14.9</td>
<td>15.4</td>
<td>15.1</td>
<td>0.22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>16.3</td>
<td>16.0</td>
<td>17.0</td>
<td>16.7</td>
<td>0.27</td>
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<td></td>
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</tr>
<tr>
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<td>16.1</td>
<td>16.6</td>
<td>17.1</td>
<td>17.3</td>
<td>0.22</td>
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</tr>
<tr>
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<td>16.6</td>
<td>17.2</td>
<td>17.1</td>
<td>0.15</td>
<td>0.257</td>
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<td>16.9</td>
<td>16.7</td>
<td>0.22</td>
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<tr>
<td>Summer</td>
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<td>16.6</td>
<td>17.6</td>
<td>17.3</td>
<td>0.26</td>
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<td></td>
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<tr>
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<td>17.2</td>
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<tr>
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<td>0.008</td>
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<td>17.2</td>
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<tr>
<td>Summer</td>
<td>17.3</td>
<td>16.9</td>
<td>18.1</td>
<td>17.5</td>
<td>0.27</td>
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<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>16.5</td>
<td>16.8</td>
<td>17.4</td>
<td>17.6</td>
<td>0.21</td>
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<tr>
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<td>1.3</td>
<td>1.4</td>
<td>0.16</td>
<td>0.746</td>
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<td>0.2</td>
<td>0.24</td>
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<td>3.0</td>
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<td></td>
</tr>
<tr>
<td>Genotype</td>
<td>Holstein-Friesian</td>
<td>Jersey x Holstein-Friesian</td>
<td>Norwegian Red x Jersey x Holstein-Friesian</td>
<td>SE</td>
<td>Genotype</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------</td>
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<td>--------------------------------------------</td>
<td>-----</td>
<td>----------</td>
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</tr>
<tr>
<td>Pasture dry-matter intake (kg)</td>
<td>16.5</td>
<td>16.2</td>
<td>15.9</td>
<td>0.15</td>
<td>0.039</td>
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<tr>
<td>Spring</td>
<td>15.6</td>
<td>15.0</td>
<td>15.1</td>
<td>0.20</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>16.6</td>
<td>16.7</td>
<td>16.1</td>
<td>0.24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>17.2</td>
<td>17.0</td>
<td>16.5</td>
<td>0.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total dry-matter intake (kg)</td>
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<td>0.042</td>
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<td>16.7</td>
<td>0.20</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>17.1</td>
<td>17.2</td>
<td>16.7</td>
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</tr>
<tr>
<td>Autumn</td>
<td>17.2</td>
<td>17.1</td>
<td>16.6</td>
<td>0.20</td>
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<td></td>
</tr>
<tr>
<td>Daily energy intake (UFL/day)</td>
<td>17.6</td>
<td>17.4</td>
<td>17.1</td>
<td>0.14</td>
<td>0.056</td>
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<tr>
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<td>17.5</td>
<td>0.20</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>17.6</td>
<td>17.7</td>
<td>17.1</td>
<td>0.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>17.3</td>
<td>17.2</td>
<td>16.7</td>
<td>0.20</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Daily energy balance (UFL/day)</td>
<td>1.4</td>
<td>1.6</td>
<td>1.5</td>
<td>0.14</td>
<td>0.634</td>
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</tr>
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<td>0.6</td>
<td>0.7</td>
<td>0.21</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>0.9</td>
<td>1.4</td>
<td>1.2</td>
<td>0.26</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>2.6</td>
<td>2.6</td>
<td>2.5</td>
<td>0.21</td>
<td></td>
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</tbody>
</table>
Table 6.8 Comparison of cow parity on total and pasture dry-matter intake, energy intake and energy balance

<table>
<thead>
<tr>
<th></th>
<th>Parity 1</th>
<th>Parity 2</th>
<th>Parity 3+</th>
<th>SE</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasture dry-matter intake (kg)</td>
<td>13.8</td>
<td>16.7</td>
<td>18.1</td>
<td>0.14</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Spring</td>
<td>12.5</td>
<td>15.8</td>
<td>17.4</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>13.9</td>
<td>17.0</td>
<td>18.5</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>15.0</td>
<td>17.3</td>
<td>18.5</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Total dry-matter intake (kg)</td>
<td>14.5</td>
<td>17.4</td>
<td>18.9</td>
<td>0.13</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Spring</td>
<td>14.1</td>
<td>17.3</td>
<td>19.0</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>14.5</td>
<td>17.5</td>
<td>19.1</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>15.0</td>
<td>17.4</td>
<td>18.5</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Daily energy intake (UFL/day)</td>
<td>14.9</td>
<td>17.8</td>
<td>19.3</td>
<td>0.13</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Spring</td>
<td>14.7</td>
<td>18.1</td>
<td>19.9</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>14.9</td>
<td>18.0</td>
<td>19.5</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>15.1</td>
<td>17.5</td>
<td>18.5</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>Daily energy balance (UFL/day)</td>
<td>0.9</td>
<td>1.7</td>
<td>1.8</td>
<td>0.14</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Spring</td>
<td>-0.2</td>
<td>0.9</td>
<td>1.3</td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>0.7</td>
<td>1.5</td>
<td>1.4</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>2.3</td>
<td>2.8</td>
<td>2.7</td>
<td>0.21</td>
<td></td>
</tr>
</tbody>
</table>
Table 6.9 Comparison of cow genotype on total dry-matter intake, energy intake, BW and production efficiencies

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Holstein-Friesian</th>
<th>Jersey x Holstein-Friesian</th>
<th>Norwegian Red x Jersey x Holstein-Friesian</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total DMI (TDMI; kg)$^1$</td>
<td>17.2</td>
<td>17.0</td>
<td>16.7</td>
<td>0.15</td>
</tr>
<tr>
<td>Energy intake (UFL)</td>
<td>17.6</td>
<td>17.4</td>
<td>17.1</td>
<td>0.14</td>
</tr>
<tr>
<td>TDMI/100 kg BW (kg)</td>
<td>3.36</td>
<td>3.63</td>
<td>3.45</td>
<td>0.032</td>
</tr>
<tr>
<td>SCM/100 kg BW (kg)</td>
<td>4.51</td>
<td>4.96</td>
<td>4.63</td>
<td>0.057</td>
</tr>
<tr>
<td>Milk solids/100 kg of BW (kg)</td>
<td>0.35</td>
<td>0.39</td>
<td>0.37</td>
<td>0.005</td>
</tr>
<tr>
<td>Milk solids/TDMI (kg)</td>
<td>0.106</td>
<td>0.108</td>
<td>0.107</td>
<td>0.001</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>514</td>
<td>470</td>
<td>485</td>
<td>4.5</td>
</tr>
</tbody>
</table>

$^1$ DMI = Dry-matter intake, SCM = Solids-corrected milk
Table 6.10 Comparison of perennial ryegrass ploidy and white clover inclusion on total dry-matter intake, energy intake, BW and production efficiencies

<table>
<thead>
<tr>
<th></th>
<th>Tetraploid</th>
<th>Diploid</th>
<th>Tetraploid + white clover</th>
<th>Diploid + white clover</th>
<th>SE</th>
<th>Ploidy</th>
<th>White clover</th>
<th>Ploidy* WC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total DMI (TDMI; kg)¹</td>
<td>16.8</td>
<td>16.6</td>
<td>17.2</td>
<td>17.1</td>
<td>0.153</td>
<td>0.26</td>
<td>0.002</td>
<td>0.549</td>
</tr>
<tr>
<td>Energy intake (UFL)</td>
<td>17.3</td>
<td>17.0</td>
<td>17.7</td>
<td>17.5</td>
<td>0.152</td>
<td>0.09</td>
<td>0.008</td>
<td>0.702</td>
</tr>
<tr>
<td>TDMI/100 kg BW (kg)</td>
<td>3.43</td>
<td>3.45</td>
<td>3.54</td>
<td>3.51</td>
<td>0.034</td>
<td>0.969</td>
<td>0.013</td>
<td>0.357</td>
</tr>
<tr>
<td>SCM/100 kg BW (kg)</td>
<td>4.57</td>
<td>4.59</td>
<td>4.90</td>
<td>4.75</td>
<td>0.055</td>
<td>0.219</td>
<td>&lt;0.001</td>
<td>0.055</td>
</tr>
<tr>
<td>Milk solids/100 kg of BW (kg)</td>
<td>0.36</td>
<td>0.36</td>
<td>0.39</td>
<td>0.37</td>
<td>0.004</td>
<td>0.165</td>
<td>&lt;0.001</td>
<td>0.029</td>
</tr>
<tr>
<td>Milk solids/TDMI (kg)</td>
<td>0.105</td>
<td>0.106</td>
<td>0.110</td>
<td>0.108</td>
<td>0.001</td>
<td>0.564</td>
<td>0.006</td>
<td>0.236</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>495</td>
<td>487</td>
<td>488</td>
<td>489</td>
<td>4.499</td>
<td>0.22</td>
<td>0.426</td>
<td>0.097</td>
</tr>
</tbody>
</table>

¹ DMI = Dry-matter intake, SCM = Solids-corrected milk
6.5 Discussion

A major limiting factor affecting milk production from grazed pasture is dairy cow DMI (Bargo et al., 2002; Dillon, 2007). Pasture-based systems aim to maximise daily herbage intake per cow, while also maintaining a high-quality pasture throughout the grazing season.

6.5.1 Effect of sward type on dry-matter intake

Sward type has previously been shown to have a large influence on DMI, with effects observed between PRG cultivar, ploidy, heading dates, pre-grazing herbage mass and white clover inclusion. The current study also observed the white clover response, but not the ploidy response that might have been expected. It is notable that Gowen et al., (2003) compared four PRG cultivars for grass DMI at three time-points in the grazing season and observed higher DMI from tetraploid compared to diploid cultivars at two time-points (corresponding to grazing rotation five and seven) and in the absence of nutritive value differences which is in agreement with the present study. Latinga and Groot (1996) also observed similar increases in DMI and hypothesised that there is a positive relationship between high leaf content and DMI, which can be amplified in tetraploid cultivars. Furthermore, previously observed ploidy differences in DMI have been accounted for by a higher palatability and possibly a lower resistance to chewing for tetraploids due to their higher leaf: stem ratio (Latinga and Groot et al., 1996; Gowen et al., 2003). This has more recently been confirmed by Guy et al. (2018b), who reported greater leaf proportion for tetraploid swards. It has been further hypothesised that there is a relationship between water-soluble carbohydrate (WSC) content and DMI, with WSC content typically higher in tetraploid cultivars compared to diploids (Byrne et al., 2018). However, this may not be an essential factor as Lantinga and Groot (1996) reported similar WSC levels in tetraploid and diploid cultivars but still observed higher DMI from tetraploids. Furthermore, Tas et al. (2005) found no difference in DMI between eight diploid PRG cultivars despite differences in WSC content. Another possible DMI driving factor is pre-grazing herbage mass as it has previously been reported that cows grazing the same herbage allocations but at a lower PrGHM had higher DMI compared to those offered a higher PrGHM (Roca-Fernández et al., 2011; Wims et al., 2014). This is probably because cows offered lower PrGHM have been shown to graze lower into the sward (Curran et al., 2010), possibly due to higher nutritive value in the base of the sward and a lower level of dead material compared to swards with higher PrGHM. While the diploid swards in the present study had higher PrGHM compared to tetraploids, the differences
were not as extreme as Roca-Fernández et al. (2011) and this is reflected in the similar nutritive values recorded between ploidy. Therefore previous research presents a complexity of interacting factors which provides no clear explanations for the absence of ploidy differences in DMI in the current study.

The inclusion of white clover in grazing swards typically increases nutrient value and voluntary DMI (Frame and Newbould, 1984; Harris et al., 1997; Ribeiro Filho et al., 2003). Harris et al. (1997) showed that in white clover swards, cows had a significant increase in DMI when white clover content was at 50% compared to 20%, with no difference in DMI between swards with 50 and 80% white clover. Ribeiro Filho et al. (2003) found cows grazing swards with 40% white clover had 1.5 kg DM/cow per day increase in DMI compared to cows grazing PRG-only swards. Therefore, the clear increase in DMI from white clover swards in the present study corroborates these previous publications. This also explains why there was no difference in DMI in spring, when clover content was low and the DMI response when clover content increased in summer and autumn. This clover driven higher DMI has been linked to a faster rumen passage rate of white clover tissue compared to PRG herbage, due to a lower NDF and ADF content (Minson, 1990; Egan et al., 2018). It has also been suggested that DMI could be predicted by calculating dietary NDF (Mertens, 1987), relating NDF to the bulk density of forage. Therefore in swards with lower NDF content such as PRG-white clover, DMI could be higher, as with fibrous diets, intake can be limited by rumen capacity and by the passage rate of digesta through the rumen (Minson, 1990). Nonetheless, some previous studies have reported no increase in DMI from PRG-white clover swards (Thomson et al., 1985; Egan et al., 2017), but did still find an increase in milk production. They attributed this to the increase in nutritive value from PRG-white clover swards compared to PRG-only, and in particular to the lower NDF content. Beauchemin (1991) reported that as diet NDF concentration increased, a linear decrease in daily milk production occurs. In Chapter 4, total feed intake per cow during lactation was calculated and showed that cows consumed 320 kg more DM from PRG-white clover than from PRG-only and attributed 68% of the increase in MS produced (+ 32 kg) to increased DMI, with the remaining 32% likely due to the increase in sward nutritive value and associated benefits. These studies therefore substantiate a causal factor for the increase in milk production in the current study, namely additional energy intake for cows grazing PRG-white clover swards.
6.5.2 Effect of cow genotype on dry-matter intake

The influence of animal genotype on DMI in pasture-based systems not only occurs through the animals’ ability to consume greater quantities of pasture, but also through the capacity of the animal to calve annually at a time that facilitates the maximum amount of grazed herbage to be incorporated in that animal’s diet (Dillon, 2007). Milk yield, feed intake and energy balance have been shown to be heritable traits, and that selection for higher yields can increase DMI, in addition to increasing the energy gap between yield and DMI (Veerkamp, 1998). This relationship was observed in the current study with HF cows having the highest milk yield and TDMI. Selection for lower BW to increase feed efficiency is also obvious as there is no doubt that smaller cows have lower feed requirements for maintenance such as the JEX and 3WAY cows in this study (Veerkamp, 1998). Grazing systems require animals that are capable of achieving large intakes of forage so that they are able to meet their requirements almost entirely from grazed forage (Dillon, 2007). There is strong evidence to show that cows that are genetically best suited to confinement systems are not best suited to grazing systems, with an interaction observed between genotype and feeding system (Dillon et al., 2006; Horan et al., 2005b; Coleman et al., 2010). In the current study significant differences in TDMI and PDMI were found between the three cow genotypes. Prendiville et al. (2009) also compared HF and F1 HF x Jersey cows for DMI in a pasture-based system. Mean DMI was higher with HF (16.9 kg/cow per day) compared to JEX cows (16.2 kg/cow per day). Similarly, Coffey et al. (2017) found HF cows had an additional 0.6 kg DMI compared to F1 HF x Jersey cows (16.5 vs. 15.9 kg DMI/d. respectively). Both studies found larger differences in DMI between HF and JEX than what was recorded in the current study. Ferris et al. (2018) compared full lactation DMI of Holstein and Swedish Red X Jersey X Holstein cows and although Holsteins had higher DMI in early lactation, both breeds were similar for full lactation DMI. This is in contrast to the higher DMI for HF cows compared to 3WAY cows observed in the current study, however as the 3WAY breed is not the same as in Ferris et al. (2018) study, it is not directly comparable.

6.5.3 Effect of cow parity on dry-matter intake

It is well established that the physiological state of an animal will influence the amount of energy it consumes and eventually utilise, therefore any effect of the physiological state on abdominal capacity will affect intake, e.g. young, fat or pregnant animals will have a reduced intake capacity compared to older, thin or non-pregnant animals (Bines, 1976). Jarrige et al.
(1986) developed a voluntary DMI prediction equation using ‘fill values’ of diets, which is particularly important in pasture-based systems. They found parity 1 animals had an intake capacity of approximately 80% of multiparous cows in grazing systems. The current study found total DMI of 14.5, 17.4 and 18.9 kg/cow per day for parity 1, 2 and 3 + cows respectively, which is consistent with current knowledge on how a cow’s performance changes over concurrent lactations. Bines (1976) had similar differences between parities, with DMI of 13.7, 15.8 and 16.7 kg/cow per day for parity 1, 2 and 3 cows, respectively. Kennedy et al. (2003) observed higher DMI values when comparing cows in pasture-based systems receiving differing levels of concentrate supplementation, with TDMI of 14.9, 17.7 and 20.9 kg/cow per day for parity 1, 2 and 3+, respectively. Similarly Buckley et al. (2000) compared high and medium genetic merit cows throughout the first three years of lactation and again found clear increases in DMI between primiparous and multiparous cows (15.7 vs. 19.6 kg/cow per day, respectively).

6.5.4 Milk production efficiency

The JEX cows in this study had a higher DMI/100 kg BW than the HF cows (3.63 and 3.39 kg of DM, respectively), which is similar to results observed by Gonzalez-Verdugo et al. (2005). Vance at al. (2010) also found higher DMI per BW in F1 Jersey x HF cows compared to HF cows, which were on average 75 kg heavier. These studies are in contrast to the current study where there were significant differences between genotypes for TDNI, however when energy balance is considered there were no differences between genotypes. Prendiville et al. (2009) explored the same production efficiencies with similar results for TDNI/100 kg BW for HF (3.39 kg) and JEX cows (3.63 kg), and slightly lower but relative MS/100 kg BW for HF (0.27 kg) and JEX cows (0.32 kg). Furthermore, Coffey et al. (2017) found as a percentage of BW, JEX cows had higher DMI and higher FCE, but overall a lower DMI compared to HF cows. They also reported similar energy balances between genotypes as was seen in the present study, reflecting the lower DMI of JEX cows but also their lower maintenance energy requirement compared to HF. Production efficiencies between genotypes were also reported by Coffey et al. (2017) and were comparable to the current study, with similar TDNI/100 kg BW for HF (3.30 kg) and JEX cows (3.55 kg), and also similar MS/100 kg BW for HF (0.35 kg) and JEX cows (0.39 kg). Very few studies have examined DMI or production efficiencies for any 3-way rotation breeds. One such study, by Shonka-Martin et al. (2018), recently compared a rotational crossbred of Montbéliarde x Viking Red x Holstein with Holstein cows for DMI. They found
lower DMI from crossbreds compared to HF cows from 4 to 150 DIM in their first three lactations, with similar MS production, higher BCS and similar BW. It can be assumed that the crossbreds from this study were more efficient compared to the Holsteins as they consumed less feed while producing similar MS output and at the same BW. It is hard to compare them to the 3WAY crossbreds used in this study, as the BW for both crossbreds were significantly lower compared to the HF cows.

6.6 Conclusion

The results of this study show that significant increases in DMI and higher nutritive value can be gained from using PRG-white clover swards rather than PRG-only swards, and that this can ultimately sustain increased milk and MS yields. The driving factors for these increases are greater efficiency in TDMI/100 kg BW, SCM/100 kg BW and MS/100 kg of BW that result from white clover being included in the swards. The study also shows that cow genotype is important as it influences DMI and production efficiency with regards to cow BW and MS production. Under the imposed pasture-based system, JEX cows were the most efficient for TDMI/100 kg BW, SCM/100 kg BW and MS/100 kg of BW.
Chapter 7
Economic comparison of pasture-based production systems differing in sward type and cow genotype

7.1 Summary
The objective of this chapter was to compare the economic performance of 2 sward types (PRG sown with or without white clover) grazed by three different cow genotypes. Physical performance data was collected from a four year systems experiment based at Clonakilty Agricultural College, Clonakilty, Co. Cork. The experiment compared two sward types: PRG-only swards and PRG-white clover swards, with each sward type being grazed by three cow genotypes; Holstein-Friesian (HF), Jersey × HF (JEX) and Norwegian Red × JEX. All systems were stocked at 2.75 cows/ha with cows receiving the same amount of concentrate supplementation and nitrogen application rate. The data supplied six production systems; two sward types and three genotypes and the economic performance of these systems was modelled using the Moorepark Dairy Systems Model (stochastic budgetary simulation model). The production scenarios analysed included a scenario where cow numbers were fixed and another where land area was fixed. The analysis was completed across a range of milk prices, calf prices and reseeding programs. The analysis shows that adding white clover to PRG swards increased profitability by €305/ha in the fixed land scenario with a milk price of 29c/l across cow genotype. In the same fixed land scenario, JEX cows were most profitable (€2,606/ha), followed by 3WAY (€2,492/ha) and HF (€2,468). The system that produced the highest net profit was JEX cows grazing PRG-white clover swards (€2,751/ha).

7.2 Introduction
With the recent abolition of milk quotas in the EU, there has been a large increase in milk production in Ireland driven by an increase in cow numbers and milk yield per cow (Läpple and Sirr, 2019). Dairy production systems in Ireland are primarily pasture-based and factors such as soil type (Shalloo et al., 2004a), stocking rate (Macdonald et al., 2008), grazing season length (Läpple et al., 2012b) and supplementary feed use (Ramsbottom et al., 2015; Macdonald et al., 2017; Hanrahan et al., 2018) can affect the efficiency and profitability of these systems. However, it is acknowledged that pasture use (Hanrahan et al., 2018; Ramsbottom et al., 2015)
and cow genotype (McCarthy et al., 2007; Prendiville et al., 2011b) are two of the main factors that affect profitability within pasture-based dairy production systems.

Perennial ryegrass is the main grass species grown in temperate regions of the world and is the cheapest feed available for dairy cows (McGilloway, 2005; Finneran et al., 2012). However, there has been renewed interest in including forage legumes, particularly white clover in PRG swards due to its ability to biologically fix nitrogen N, reduce inorganic N fertiliser use while maintaining/increasing pasture DM production and pasture nutritive value (Lüscher et al., 2014; Delaby et al., 2016). Enriquez-Hidalgo et al. (2014) and Guy et al. (2018b) reported increased pasture production and utilisation with PRG-white clover swards compared to PRG-only swards at similar N fertiliser rates. Chapter 4 and other recent research has also re-emphasised the beneficial effects of white clover inclusion in PRG swards, on animal performance, as dairy cows grazing PRG-white clover swards can have higher milk yields compared to cows grazing PRG-only swards (Egan et al., 2018; McClearn et al., 2019). Schills et al. (2000a) reported that gross margin was higher per farm and per cow (although not per ha) on low N-fertilised PRG-white clover swards compared to higher N-fertilised PRG-only swards. In contrast, Humphreys et al. (2012) reported similar net margin/ha for PRG-only swards receiving high levels of artificial N compared to PRG-white clover swards receiving reduced N fertiliser annually. However, the systems used in these studies are not directly comparable as the PRG-white clover swards did not have the same N-fertiliser input levels as the PRG-only swards.

As stated previously cow genotype can have a significant impact on the profitability of pasture-based production systems due to differences in milk and MS yield, reproductive performance and functional traits (McCarthy et al., 2007). The use of crossbreeding, in order to exploit favourable characteristics of ‘alternative’ genotypes, can remove the negative effects associated with inbreeding and capitalise on heterosis. Crossbreeding has generated increased interest in the last two decades (Buckley et al., 2014). A number of studies have reported improved animal performance, both in terms of MS production, reproductive performance (Coffey et al., 2017; Vance et al., 2013; Prendiville et al., 2011a) and economic performance (Lopez-Villalobos et al., 2000; Prendiville et al., 2011b) for Jersey x Holstein-Friesian (HF) crossbred cows compared to their purebred parent genotypes in pasture-based production systems. Although Jersey x HF (JEX) are the most common crossbred found in pasture-based systems, crossbreds of Norwegian
Red, Montbéliarde and Normande with HF have been shown to have superior reproductive performance with similar or increased MS production per cow when compared with HF (Heins et al., 2006; Walsh et al., 2007; Buckley et al., 2014). The improved reproductive performance, higher survivability and increased MS yield/cow, due to a greater proportion of mature crossbred cows surviving in the herd, generally make them suitable for spring-calving pasture-based systems (Buckley et al., 2014).

In order to fully evaluate the economic impact of variations in animal performance and production as a consequence of changes in sward type and cow genotype, a multidisciplinary systems simulation approach was required. This simulation included the effects of all major farm components, including all production revenues as well as combining variable and fixed costs. The objective of this chapter was to investigate the profitability of spring-calving grazing dairy production systems differing in sward type (PRG-only or PRG-white clover) and dairy cow genotype (HF, JEX and Norwegian Red x JEX (3WAY)) under differing scenarios where land area was fixed, reflective of the situation on most Irish farms as well as where cow numbers are fixed which could be reflective of potential future restrictions at farm level. The analysis was completed across a range of milk and calf prices and reseeding programs.

7.3 Materials and Methods

7.3.1 Production study details

The Moorepark dairy systems model used the biological data from Chapter 4 and 5 to complete the economic analysis. The experiment was a randomised block design with a 2 x 2 factorial arrangement of treatments creating four grazing treatments, a tetraploid PRG-only sward (TGO), a diploid PRG-only sward (DGO), a tetraploid PRG sward with white clover (TWC) and a diploid PRG sward with white clover (DWC). However as there was no herbage or milk production difference between ploidies, an average of PRG-only (TGO and DGO) and PRG-white clover (TWC and DWC) was used in the model. Where no significant differences occurred between treatments for biological variables, an average value was included in the MDSM. The performance of the three genotypes was also used in the model (HF, JEX and 3WAY). Further detail of the experimental design and grazing treatments can be found in Chapter 3.
The parental average EBI is shown previously in Chapter 5 (Table 5.1) for all three genotypes. The parental average EBI reported was updated in January 2019 and is presented instead of actual cow values to exclude the effect of grazing treatment on individual cow performance. The overall EBI differed between genotypes, with HF at €115, JEX at €131 and 3WAY at €159. Table 7.1 shows the biological performance from the different sward types and cow genotypes such as lactation length milk production, BW, BCS, silage fed and labour per cow. Reproductive performance is not presented as it did not differ significantly between sward type or cow genotype. Therefore an average reproductive performance for all groups was used for economic analysis. Average six-week pregnancy rate was 87% and overall 12 week pregnancy rate was 94% for all three genotypes.
Table 7.1 The effect of sward type and cow genotype on milk production, BW, BCS, silage fed and labour per cow

<table>
<thead>
<tr>
<th></th>
<th>PRG-only(^1)</th>
<th></th>
<th>PRG-white clover</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HF</td>
<td>JEX</td>
<td>3WAY</td>
<td>HF</td>
</tr>
<tr>
<td>Lactation length (day)</td>
<td>282</td>
<td>285</td>
<td>279</td>
<td>283</td>
</tr>
<tr>
<td>Milk yield (kg/cow)</td>
<td>5,365</td>
<td>5,181</td>
<td>5,119</td>
<td>6,072</td>
</tr>
<tr>
<td>Fat content (%)</td>
<td>4.58</td>
<td>4.87</td>
<td>4.73</td>
<td>4.47</td>
</tr>
<tr>
<td>Protein content (%)</td>
<td>3.75</td>
<td>3.91</td>
<td>3.89</td>
<td>3.69</td>
</tr>
<tr>
<td>Milk solids(^2) yield (kg/cow)</td>
<td>447</td>
<td>455</td>
<td>441</td>
<td>495</td>
</tr>
<tr>
<td>Bodyweight (kg)</td>
<td>527</td>
<td>476</td>
<td>496</td>
<td>533</td>
</tr>
<tr>
<td>Body condition score</td>
<td>2.92</td>
<td>2.93</td>
<td>3.00</td>
<td>2.94</td>
</tr>
<tr>
<td>Silage fed/cow per year (kg DM)</td>
<td>363</td>
<td>363</td>
<td>363</td>
<td>441</td>
</tr>
<tr>
<td>Labour/cow (hours)</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>31.2</td>
</tr>
</tbody>
</table>

\(^1\)PRG = Perennial ryegrass, HF = Holstein Friesian, JEX = Jersey × Holstein Friesian, 3WAY = Norwegian Red × Jersey × Holstein Friesian

\(^2\)Milk solids = kg fat + protein
7.3.2 Economic analysis

The Moorepark Dairy Systems model (MDSM; Shalloo et al., 2004b) is a stochastic budgetary simulation model and was used to simulate a model farm using the biological data for each sward type and each cow genotype. The model integrates animal inventory and valuation, milk production, pasture production, feed requirements, land and labour utilised and an economic analysis. Land area was treated as an opportunity cost, with additional land rented when required and leased out when not required for on-farm feeding of animals. Variable costs (fertiliser, contractor charges, veterinary fees, AI and feed costs) and fixed costs (machinery running and maintenance, farm maintenance, car, telephone, electricity and insurance) were based on current prices (Teagasc, 2013). The feeds offered (grass, grass silage and concentrate) were determined by the MDSM meeting the net energy requirement, for milk production and BW change (Jarrige, 1989). Table 7.2 shows the key assumptions used in the model for the six treatments simulated.

In all simulations, all calves were sold at 1 month of age. All male calves were assumed sold for market values with a value included for the calves of the different genotypes of €53, €34 and €20 for the HF, 3WAY and JEX respectively, with all female calves included in the model at €350 each. These calf value assumptions were based on actual market values recorded throughout the study. Replacement females were bought for €1,545 based on rearing costs (Shalloo et al., 2014) and were brought onto the farm 1 month prior to calving. Cull cow values were generated based on the assumption that cows were culled directly from the milking parlour with the 3WAY and the HF cows having a killout percentage of 42% and a market carcass value of €1.50/kg while the JEX were assumed to have a killout of 40% and a market carcass value of €1.25/kg (Prendiville et al., 2011b). Labour costs were calculated based on a labour requirement of 30 hours/cow per year while 1,848 hours was considered equal to one labour unit/year, at a cost of €22,855. As a result of white clover being in the sward, there is less pasture growth over winter and subsequently lower pasture availability in spring (Guy, 2018). Therefore within the systems simulated there was a requirement for additional silage supplementation in spring to cows on PRG-white clover swards. This was included as a labour and machinery cost across the PRG-white clover treatments. The requirement for bloat oil and the infrastructure and management time to administer it was also included in the PRG-white clover treatments.
Table 7.2 Herd default parameters used in the Moorepark Dairy Systems Model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm size (ha)</td>
<td>40</td>
</tr>
<tr>
<td>Concentrate cost (€/t)</td>
<td>280</td>
</tr>
<tr>
<td>Opportunity cost of land (€/ha)</td>
<td>450</td>
</tr>
<tr>
<td>Housing costs (€/cow)</td>
<td>1617</td>
</tr>
<tr>
<td>Replacement heifer costs (€/animal)</td>
<td>1545</td>
</tr>
<tr>
<td>Labour costs (€/h)</td>
<td>12.40</td>
</tr>
<tr>
<td>Fertiliser costs: urea (€/t)</td>
<td>420</td>
</tr>
<tr>
<td>Fertiliser costs: Calcium Ammonium Nitrate (€/t)</td>
<td>320</td>
</tr>
<tr>
<td>Ratio milk value of protein to fat</td>
<td>1.5</td>
</tr>
</tbody>
</table>
7.3.3 Scenarios

With the removal of the EU milk quota system, the main limiting factors within pasture-based dairy production systems centre on land area but in the future there could be cow number restrictions depending on environmental policy. Therefore the analysis was completed with both land area and cow number restrictions included. The herds were compared across three future base milk prices of 24.0, 29.0 and 34.0 € cents per litre (c/l), assuming reference milk contents of 33.0 g/kg protein and 36.0 g/kg fat and a relative milk price ratio of 1:1.5 for fat : protein, within a multiple component (A + B - C) milk payment pricing regime (Geary et al., 2010). Sensitivity around calf prices was included where calf value differences between the HF and JEX and 3WAY were increased by €30 and €60 per calf across the board. Finally the simulations were completed where the reseeding frequency was increased from every ten years for PRG-only swards to every five years for PRG-white clover swards.

7.4 Results

7.4.1 Influence of sward type and cow genotype on farm profitability

Table 7.3 shows the effect of sward type on farm profitability in a scenario where land is limited to 40 ha and milk price is 29 c/l. Stocking rate varies for sward type as the MDSM determines the net energy requirement based on milk produced and BW changes. The PRG-white clover swards are stocked lower than PRG-only due to their higher milk yield per cow (average + 601 kg) and therefore their higher net energy requirement even though there is more pasture utilised per hectare (+ 1,080 kg DM/ha). On average the PRG-only 40 ha farm supported 119 cows while the PRG-white clover supported 116 cows. On average across all three genotypes, MS output was 105 kg MS/ha greater on PRG-white clover swards compared to PRG-only swards. Across all three genotypes, costs were €129/ha higher on PRG-white clover swards; due to higher silage and labour requirements and additional costs associated with the inclusion of bloat oil. However, profitability was on average €305/ha higher with PRG-white clover swards (€2,369 vs. €2,674 for PRG-only and PRG-white clover swards, respectively).

Table 7.3 also shows the effect of cow genotype on farm profitability. Stocking rate varies for cow genotype based on energy requirements. On average over the two sward types, 116 HF, 119 JEX or 119 3WAY cows were stocked on a 40 ha farm. Milk output averaged 1,326 kg MS/ha
for HF cows, 1,382 kg MS/ha for JEX cows and 1,346 kg MS/ha for 3WAY cows. Costs were higher for JEX and 3WAY compared to HF due to the additional cows on farm; however profitability was highest for JEX (€2,606/ha), followed by 3WAY (€2,492/ha) and HF (€2,468). The highest net profit per farm was achieved with JEX cows on PRG-white clover swards (€110,037 per farm or €2,751/ha) at a stocking rate of 2.93 cows/ha (117 cows on 40 ha). The lowest net profit per farm was achieved with HF cows on PRG-only swards (€92,136 per farm or €2,303/ha) with 117 cows on 40 ha. This resulted in a difference in net profit of €17,900/farm, €448/ha and €155/cow.
Table 7.3 The effect of sward type and cow genotype in a fixed land area (40 ha) with a milk price of 29 c/l

<table>
<thead>
<tr>
<th></th>
<th>PRG-only¹</th>
<th>PRG-white clover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HF</td>
<td>JEX</td>
</tr>
<tr>
<td>Cow numbers</td>
<td>117</td>
<td>120</td>
</tr>
<tr>
<td>Hectares</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Grass utilised (kg DM/ha)</td>
<td>13,896</td>
<td>13,896</td>
</tr>
<tr>
<td>Milk produced (kg)</td>
<td>625,522</td>
<td>620,122</td>
</tr>
<tr>
<td>Milk Output (kg MS)</td>
<td>50,875</td>
<td>53,204</td>
</tr>
<tr>
<td>Labour (€)</td>
<td>43,441</td>
<td>44,418</td>
</tr>
<tr>
<td>Gross Output (€)</td>
<td>251,404</td>
<td>260,169</td>
</tr>
<tr>
<td>Costs (€)</td>
<td>159,722</td>
<td>162,224</td>
</tr>
<tr>
<td>Net Profitability (€)</td>
<td>92,136</td>
<td>98,423</td>
</tr>
<tr>
<td>Net Profitability/cow (€)</td>
<td>787</td>
<td>822</td>
</tr>
<tr>
<td>Net Profitability/hectare (€)</td>
<td>2,303</td>
<td>2,461</td>
</tr>
<tr>
<td>Net Profitability/kg MS (€)</td>
<td>1.81</td>
<td>1.85</td>
</tr>
</tbody>
</table>

¹PRG = Perennial ryegrass, HF = Holstein Friesian, JEX = Jersey × Holstein Friesian, 3WAY = Norwegian Red × Jersey × Holstein Friesian, MS = milk solids (kg fat + protein)
7.4.2 Fixed cow numbers

Table 7.4 shows the key herd output parameters from the MDSM for the two sward types and three genotypes, when cow numbers are fixed to 114 and land used is variable with a base milk price of 29c/l. In this scenario land use varies with sward type and cow genotype due to herd demand. There was a lower land requirement for PRG-only compared to PRG-white clover swards, however, this did not make them more profitable, as the higher output from the PRG-white clover swards (milk + pasture) offset the requirement for more land area. Net farm profitability for PRG-white clover swards was €14,572 higher than PRG-only from 114 cows, €364 higher per ha and €128 higher per cow. Net farm profitability was highest for JEX cows (€99,571) compared to HF (€97,114) and 3WAY cows (€94,504). This is also reflected in profitability per ha with JEX being the most profitable (€2,489), followed by HF (€2,428) and 3WAY (€2,363). In this scenario the least profitable cows are the 3WAY due to their lower MS production compared to HF and JEX. The optimum net profit was achieved from JEX cows grazing PRG-white clover swards; €106,563/farm, €2,664/ha and €938/cow, due to a combination of higher milk output from PRG-white clover swards and higher milk value from JEX cows.
Table 7.4 The effect of sward type and cow genotype in a fixed cow numbers scenario at milk price of 29 c/l

<table>
<thead>
<tr>
<th></th>
<th>PRG-only(^1)</th>
<th>PRG-white clover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HF(^1)</td>
<td>JEX</td>
</tr>
<tr>
<td>Cow numbers</td>
<td>114</td>
<td>114</td>
</tr>
<tr>
<td>Hectares</td>
<td>39</td>
<td>38</td>
</tr>
<tr>
<td>Grass utilised (kg DM/ha)</td>
<td>13,896</td>
<td>13,896</td>
</tr>
<tr>
<td>Milk produced (kg)</td>
<td>607,349</td>
<td>588,857</td>
</tr>
<tr>
<td>Milk Output (kg MS)</td>
<td>49,397</td>
<td>50,522</td>
</tr>
<tr>
<td>Labour (€)</td>
<td>42,179</td>
<td>42,179</td>
</tr>
<tr>
<td>Gross Output (€)</td>
<td>244,100</td>
<td>247,052</td>
</tr>
<tr>
<td>Costs (€)</td>
<td>155,587</td>
<td>154,922</td>
</tr>
<tr>
<td>Net Profitability (€)</td>
<td>88,952</td>
<td>92,580</td>
</tr>
<tr>
<td>Net Profitability/cow (€)</td>
<td>783</td>
<td>815</td>
</tr>
<tr>
<td>Net Profitability/ha (€)</td>
<td>2,224</td>
<td>2,314</td>
</tr>
<tr>
<td>Net Profitability/kg MS (€)</td>
<td>1.80</td>
<td>1.83</td>
</tr>
</tbody>
</table>

\(^1\)PRG = Perennial ryegrass, HF = Holstein Friesian, JEX = Jersey × Holstein Friesian, 3WAY = Norwegian Red × Jersey × Holstein Friesian, MS = Milk Solids
7.4.3 Sensitivity analysis

Table 7.5 shows the changes in profitability when milk price varies by 5 c/l above and below the base milk price of 29 c/l (i.e. 24 c/l and 34 c/l) in a fixed land area (40 ha) scenario. The trend for PRG-white clover swards to be more profitable than PRG-only swards carried through for each milk price scenario (24 and 34 c/l; Table 7.5). At 24 c/l the PRG-white clover swards were more profitable than PRG-only swards (€1,633 vs. €1,406/ha). At 34 c/l PRG-white clover swards were + €15,241/farm, + €381/ha and + €159/cow more profitable than PRG-only swards. At 24 c/l JEX cows were most profitable (€1,583/ha), followed by 3WAY cows (€1,493) and HF cows (€1,483). Similarly, this trend carried over when milk price was 34c/l, with JEX being the most profitable (€3,614), followed by 3WAY (€3,477) and HF (€3,439). At 24 c/l there was a net profit difference of €13,244/farm, €331/ha and €144/cow between JEX on PRG-white clover and HF cows on PRG-only swards. At 34c/l the difference increased linearly with an additional profit of €22,491/farm, €562/ha and €195 per cow.
Table 7.5 The effect of sward type and cow genotype in a fixed land area (40 ha) with varying milk price (24 c/l or 34 c/l)

<table>
<thead>
<tr>
<th></th>
<th>HF&lt;sup&gt;1&lt;/sup&gt;</th>
<th></th>
<th>JEX</th>
<th></th>
<th>3WAY</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PRG-only</td>
<td>PRG-white clover</td>
<td>PRG-only</td>
<td>PRG-white clover</td>
<td>PRG-only</td>
<td>PRG-white clover</td>
</tr>
<tr>
<td>Output/farm (kg MS)</td>
<td>50,875</td>
<td>55,199</td>
<td>53,204</td>
<td>57,369</td>
<td>51,766</td>
<td>55,933</td>
</tr>
<tr>
<td>Costs/farm (€)</td>
<td>159,722</td>
<td>164,201</td>
<td>162,224</td>
<td>167,391</td>
<td>162,719</td>
<td>168,513</td>
</tr>
<tr>
<td>Output/ha (kg MS)</td>
<td>1,272</td>
<td>1,380</td>
<td>1,330</td>
<td>1,434</td>
<td>1,294</td>
<td>1,398</td>
</tr>
<tr>
<td>Costs/ha (€)</td>
<td>3,993</td>
<td>4,105</td>
<td>4,056</td>
<td>4,185</td>
<td>4,068</td>
<td>4,213</td>
</tr>
<tr>
<td>Output/cow (kg MS)</td>
<td>435</td>
<td>486</td>
<td>445</td>
<td>491</td>
<td>431</td>
<td>475</td>
</tr>
<tr>
<td>Costs/cow (€)</td>
<td>1,364</td>
<td>1,445</td>
<td>1,355</td>
<td>1,433</td>
<td>1,355</td>
<td>1,430</td>
</tr>
</tbody>
</table>

Milk Price 24c/l
| Net profit/farm (€)  | 54,372        | 64,263   | 59,005 | 67,616   | 55,317 | 64,099   |
| Net profit/cow (€)   | 464           | 565      | 493    | 579      | 461    | 544      |
| Net profit/ha (€)    | 1,359         | 1,607    | 1,475  | 1,690    | 1,383  | 1,602    |

Milk price 34c/l
| Net profit/farm (€)  | 129,373       | 145,715  | 137,291 | 151,865  | 131,672 | 146,478  |
| Net profit/cow (€)   | 1,105         | 1,282    | 1,147   | 1,300    | 1,096   | 1,243    |
| Net profit/ha (€)    | 3,234         | 3,643    | 3,432   | 3,797    | 3,292   | 3,662    |

<sup>1</sup>HF = Holstein Friesian, JEX = Jersey × Holstein Friesian, 3WAY = Norwegian Red × Jersey × Holstein Friesian, PRG = Perennial ryegrass, MS = milk solids (kg fat + protein)
Table 7.6 shows the key herd output parameters from the MDSM for the two sward types, again in the fixed land scenario, but in this case when reseeding is increased to every five years for PRG-white clover swards compared to every ten years for PRG-only swards. Increasing reseeding frequency to every five years for PRG-white clover swards increased average costs by €7,246 per farm (€181/ha) compared to PRG-only swards reseeded every ten years. Net profit was still considerably higher from the PRG-white clover swards compared to PRG-only, even with the increased reseeding cost (+ €10,089/farm and + €252/ha).
The effect of sward type and cow genotype in a fixed land area (40 ha) with a milk price of 29c/l with an increased reseeding frequency of every five years for perennial ryegrass-white clover swards vs. every ten years for perennial ryegrass-only swards

<table>
<thead>
<tr>
<th></th>
<th>HF(^1)</th>
<th>JEX</th>
<th>3WAY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PRG-only</td>
<td>PRG-white</td>
<td>PRG-only</td>
</tr>
<tr>
<td>Reseed every five years</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross output (kg MS)</td>
<td>50,875</td>
<td>55,199</td>
<td>53,204</td>
</tr>
<tr>
<td>Costs (€)</td>
<td>159,722</td>
<td>166,301</td>
<td>162,224</td>
</tr>
<tr>
<td>Net profit/farm (€)</td>
<td>92,136</td>
<td>103,176</td>
<td>98,423</td>
</tr>
<tr>
<td>Net profit/cow (€)</td>
<td>787</td>
<td>908</td>
<td>822</td>
</tr>
<tr>
<td>Net profit/ha (€)</td>
<td>2,303</td>
<td>2,579</td>
<td>2,461</td>
</tr>
</tbody>
</table>

\(^1\)HF = Holstein Friesian, JEX = Jersey × Holstein Friesian, 3WAY = Norwegian Red × Jersey × Holstein Friesian, PRG = Perennial ryegrass, MS = milk solids (kg fat + protein)
Table 7.7 shows the key herd output parameters from the MDSM for the three cow genotypes, in the fixed land scenario with a milk base price of 29c/l, when calf value varies. In this scenario HF and 3WAY male calf values are modelled with the original prices included (€53, €34 and €20 for HF, 3WAY and JEX, respectively), in addition the value of the HF and 3WAY male calves increased + €30 and + €60 compared to JEX calves. The impact of the higher value male calves from HF and 3WAY cows results in the profit of the HF group increasing by €1,957 per farm and €49 per ha and for the 3WAY cow increasing by €2,018 per farm and €50 per ha for the increase in the differential of €30 scenario. The corresponding figures for the increase in differential of €60 are €3,915 per farm and €98 per ha for HF and €4,037 per farm and €101 per ha for 3WAY cows. Even at an increase in differential of €60 the JEX animals are still most profitable on a per ha basis (€2,606 compared to €2,566 and €2,593 for HF and 3WAY, respectively).
Table 7.7 The effect of sward type and cow genotype in a fixed land area (40 ha) with milk price of 29 c/l with varying calf sale values (+ €30 or + €60 for HF and 3WAY compared to JEX)

<table>
<thead>
<tr>
<th></th>
<th>HF(^1)</th>
<th>JEX</th>
<th>3WAY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PRG-only</td>
<td>PRG-white</td>
<td>PRG-only</td>
</tr>
<tr>
<td>Calf price + €30 (HF + 3WAY)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net profit/farm (€)</td>
<td>94,122</td>
<td>107,204</td>
<td>98,423</td>
</tr>
<tr>
<td>Net profit/cow (€)</td>
<td>804</td>
<td>943</td>
<td>822</td>
</tr>
<tr>
<td>Net profit/ha (€)</td>
<td>2,353</td>
<td>2,680</td>
<td>2,461</td>
</tr>
<tr>
<td>Calf price + €60 (HF + 3WAY)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net profit/farm (€)</td>
<td>96,109</td>
<td>109,132</td>
<td>98,423</td>
</tr>
<tr>
<td>Net profit/cow (€)</td>
<td>821</td>
<td>960</td>
<td>822</td>
</tr>
<tr>
<td>Net profit/ha (€)</td>
<td>2,403</td>
<td>2,728</td>
<td>2,461</td>
</tr>
</tbody>
</table>

\(^1\)HF = Holstein Friesian, JEX = Jersey × Holstein Friesian, 3WAY = Norwegian Red × Jersey × Holstein Friesian, PRG = Perennial ryegrass, MS = Milk Solids
7.5 Discussion

7.5.1 Factors driving farm profitability

There are numerous factors that contribute to the profitability of dairy farm systems. In temperate regions, grazed grass is considered the cheapest feed available for dairy cows, and the suitability of Ireland’s climate for forage production has given it a competitive advantage to produce high quality milk from low cost grazed herbage (Dillon et al., 2005; Finneran et al., 2012). There are also benefits to Ireland’s pasture-based systems compared to the globally more common indoor total mixed ration feeding system. Many studies have found pasture-based systems to be more sustainable (financially and environmentally) with grazing dairy cows converting non-human edible protein into high quality dairy products (Ferris, 2007; Acosta-Alba et al., 2012; O’Brien et al., 2014). There are also benefits based on consumer perceptions of the dairy industry that grazing systems are more sustainable, have higher animal welfare and produce higher quality dairy products (Dillon et al., 2005; Peyraud et al., 2010). Therefore, to improve the efficiency of pasture-based systems, the utilisation and production of grazed grass should be maximised, while variable costs such as concentrate feed should be minimised to increase farm profitability (Macdonald et al., 2017; Hanrahan et al., 2018). Individual animal productivity is also a contributor, which is influenced by environment, management and genetic potential (Kearney et al., 2004; Hanrahan et al., 2018). Ultimately whole farm profitability relies mainly on pasture utilisation, milk production per cow, stocking rate and levels of supplementation (Hanrahan et al., 2018). This study highlights the impact sward type and cow genotype can have on farm profitability within an already efficient spring-calving pasture-based production system.

7.5.2 Influence of sward type on farm profitability

Previous studies have shown that there is potential to improve pasture utilisation in Ireland (Creighton et al., 2011; Kelly et al., 2013) which is an important factor for profitability when land area is limited. The use of legume forages, and white clover in particular, in PRG swards has the potential to reduce the consumption of artificial N, reduce the carbon footprint of dairy systems and increase pasture DM production and utilisation and the nutritional value of forage (Lüscher et al., 2014; O’Brien et al., 2014; McClearn et al., 2019). There are multiple studies confirming the biological results of the current study that clearly show the benefits of white
clover inclusion in PRG swards in terms of herbage nutritive value (Beever et al., 1985; Søegaard, 1993; Enriquez-Hidalgo et al., 2018), pasture DM production (Enriquez-Hidalgo et al., 2015; Rodriguez, 2016) and milk production from grazing animals (Woodward et al., 2001; Cosgrove et al., 2006; Egan et al., 2018). The significant increase in pasture production and utilisation for PRG-white clover swards at the same N application rate as PRG-only swards (+1,080 kg DM/ha; Table 7.3) from the current study is in agreement with the previous studies. Egan et al. (2018) compared PRG-white clover and PRG-only swards receiving 250 kg N each and showed that the PRG-white clover sward produced 887 kg DM additional herbage and the cows produced an additional 33 kg MS/cow per year. Typically lower levels of N are applied to PRG-white clover swards to encourage BNF and increase the competitiveness of white clover (Brock, 2006; Dineen et al., 2018). The additional costs of managing PRG-white clover swards compared to PRG-only swards (such as feeding more silage in spring and the higher labour requirement for feeding this silage along with the grazing management of paddocks with high white clover content for bloat management) were included in this analysis, but in previous studies costs were typically lower with PRG-white clover swards due to reduced fertiliser application (Schils et al., 2000a; Humphreys et al., 2012). Humphreys et al. (2012) compared high N input PRG swards with lower N input PRG-white clover swards and found the PRG swards to be more profitable due to higher output in milk sales combined with a higher stocking rate on PRG swards compared to PRG-white clover swards. Similarly, Schills et al. (2000a) also found a 10% lower gross margin per ha (but higher gross margin per cow) for PRG-white clover swards compared to PRG-only. However, both of these studies had lower N application rates for PRG-white clover swards compared to PRG-only swards so are not directly comparable to the current study.

7.5.3 Reseeding Frequency and White Clover Persistence

Due to the reduction in sward white clover content over the four year study period (reducing from 37% in year one to 14% in year four; McClearn et al., 2019; Guy et al., 2018b) an increased reseeding frequency, in order to maintain sward white clover content, was modelled to observe the effects on farm profitability. Reseeding of PRG-only swards typically occurs after a ten year period in higher performing grassland farms in Ireland (O'Donovan et al., 2017). The persistency of PRG within the sward is a key consideration and is now included in the Pasture Profit Index (PPI; O Donovan et al., 2017). Although reseeding every five years versus ten years
significantly increased costs (+ €181/ha), net profit was still greater for PRG-white clover swards (+ €252/ha) compared to PRG-only swards, thereby making the additional effort and investment financially worthwhile. Shalloo et al. (2011) completed an economic analysis based on reseeding rates and found increased farm profitability from higher annual reseeding rates, associated with increased pasture utilisation and stocking rate. Creighton et al. (2011) also found that higher stocked dairy farms had higher reseeding rates. PRG-white clover swards in this study (Chapter 4; McClearn et al., 2019) had significantly higher pasture production and utilisation compared to PRG-only swards (+ 1,205 kg DM/ha and 1,080 kg DM/ha, respectively). However, this additional herbage was produced in the summer months and mainly conserved as silage and subsequently fed when there was a herbage deficit in spring due to lower over-winter growth on PRG-white clover swards (Chapter 4; Guy, 2018; McClearn et al., 2019).

7.5.4 The Influence of cow genotype on farm profitability

Previous studies have clearly illustrated the effect of cow genotype and genetic potential for milk production on farm profitability (Shalloo et al., 2004c; McCarthy et al., 2007; Ramsbottom et al., 2012). McCarthy et al. (2007) found that for pasture-based systems the most profitable cow type is one which has been selected for both production and fertility traits compared to those selected purely for production, highlighting the requirement for good reproductive performance in pasture-based systems. Poor reproductive performance negatively effects profitability through reduced milk yields, increased culling and replacements costs, which is exacerbated in spring calving systems (Shalloo et al., 2014). The improvements in reproductive performance from crossbred animals compared to traditional HF cows have been well documented (Prendiville et al., 2011a; Vance et al., 2013; Ferris et al., 2014). Prendiville et al. (2011b) found JEX cows to be €184 more profitable per cow compared to HF cows, due to better reproductive performance and a higher milk value. However, as shown in Chapter 5 there were no differences between the three genotypes for reproductive traits. The reproductive performance of the HF cows in this study matched both of the crossbreds for key performance indicators such as six and 12 week pregnancy rates from the four year biological study which is in contrast to previous studies. The results of the current study show that within the economic scenarios modelled on an Irish pasture-based system that JEX cows were most profitable in every scenario (whole farm, per ha and per cow) when compared to HF and 3WAY cows. These results are achieved through the higher milk price paid for higher fat and protein content milk, which is evident in crossbred
herds (Coffey et al., 2018) and the increased stocking rates possible with both crossbred cows (JEX and 3WAY; Coffey et al., 2018), and was despite the lack of an effect of genotype on reproductive performance. The higher stocking rate possible for crossbred animals is based on their lower BW resulting in lower maintenance requirements, and has been previously illustrated (Baudracco et al., 2010; Coffey et al., 2018). Additionally the higher value milk from similar crossbred animals used in this study has also been well reported before, in particular Jersey crossbreds, as they have a much higher milk fat and protein content compared to HF cows (Heins et al., 2008b; Prendiville et al., 2011a; Coffey et al., 2016) but also from Norwegian Red crossbred animals (Heins et al., 2006; Walsh et al., 2008; Ferris et al., 2014). Although the difference in net profit per cow in this study is less than the €184 reported by Prendiville et al. (2011b) there is still a benefit to crossbreeding within pasture-based production systems both economically and in terms of milk production efficiency (Chapter 5 and 6). When HF, JEX and 3WAY cows are compared in terms of EBI and economic performance, both crossbred cows (JEX and 3WAY) had higher EBI compared to HF (€131 and €159 vs. €115; Table 5.2) and were also more profitable on a per cow basis. Ramsbottom et al. (2012) examined the relationship between herd EBI and farm profitability and concluded that herds with higher genetic merit for overall profitability were more profitable, with a €1.94/cow change in net margin for every one unit change in EBI.

### 7.5.5 Value of the bull calf

The inclusion of a differing calf prices for each genotype was taken into consideration for this comparison as the low value of Jersey bull calves is often of interest to farmers when making breeding decisions. Large retailers, conscious of the attitudes and opinions of their consumers are encouraging their farmer suppliers to improve animal welfare with calf mortality and age at slaughter an area of concern (Mee, 2013). In Ireland, the predominant breed for dairy herds is HF, and bull calves are usually sold to be fattened for beef production or exported live. However, the use of Jersey bulls in breeding strategies has caused an issue with selling bull calves due to their smaller size and poor capacity for meat production, which accumulates into a negative perception for beef finishing farmers (Nielsen and Thamsborg, 2002; Berry et al., 2018). In a beef finishing study, when JEX bull calves were compared with HF bull calves, carcass weight was reduced by 12% and a poorer carcass conformation was observed (McNamee et al., 2015). However, McNamee et al. (2015) also found that Norwegian Red x HF bull calves
had a similar beef production potential to HF bull calves, with superior carcass conformation at slaughter. The base assumption in the model was €53, €34 and €20 for the HF, 3WAY and JEX bull calves respectively, this was based on actual market values from the four year study (2014-2017). As part of the sensitivity analysis, the calf price difference was increased by + €30 or + €60 for both HF and 3WAY calves compared to JEX calves, to reflect the lower demand for JEX bull calves. This resulted in a lower profitability per cow for JEX (€882) compared to HF cows (€891), however this was not reflected on a per farm or per ha basis as JEX cows can be stocked higher than HF cows due to their lower BW and energy requirement. Therefore, when land area is the limiting factor, both crossbred cows were more profitable than HF cows regardless of calf value. This illustrates the low impact that calf value has on the profitability of dairy farms as the main source of income is from milk sales (Lopez-Villalobos et al., 2000).

7.6 Conclusion

The results of this MDSM simulation reveal a higher dairy production profitability when white clover is included in PRG-only swards, even when the higher costs incurred through white clover management are fully taken into consideration. The simulation also showed JEX cows to be the most profitable cow genotype when land area or cow numbers are limited, regardless of milk price or bull calf value. Therefore, the system that had the highest profitability in this simulation was JEX cows grazing PRG-white clover swards.
Chapter 8 General Discussion

8.1 Sward Type

Demand for milk products is projected to double between 2000 and 2050 (Gerber et al., 2010; Thomas, 2018). Recent studies suggest that annual global greenhouse gas (GHG) emissions will have to be cut by up to 80% (relative to 1990 levels) before 2050 to prevent the worst effects of climate change (Fisher et al., 2007; Olivier et al., 2017). As cattle are major contributors to the GHG’s methane and nitrous oxide, this presents an acute conflict between two critical interests, human nutritional need and environmental protection. Thus, if dairy farming is to increase its supply to meet demand then there is a need for not only efficient but also sustainable farming practices (Van Vuuren and Chilibroste, 2013). The suitability of Ireland’s climate for forage production has given it a competitive advantage over many regions, as it supports the production of high quality milk from low cost grazed pasture. Dairy farmers in temperate regions such as Ireland and New Zealand aim to increase profits by minimising production costs through maximising the proportion of grazed pasture in the diet of lactating cows (Shalloo et al., 2004c; Basset-Mens et al., 2009). A link exists between economic performance and environmental sustainability, as optimising resource use has the potential to maximise the profitability of pasture-based dairy systems, and improve the environmental sustainability of milk production.

Perennial ryegrass is one of the most important grass species grown in temperate pastoral regions of the world (McGilloway, 2005). Diploid and tetraploid PRG cultivars differ in nutritional value and growth habit, with tetraploid cultivars having a higher proportion of cellular content that provide a higher concentration of WSC, protein and lipids, and improves digestibility while also having a larger leaf size but fewer tillers than diploid cultivars (Smith et al., 2001). Similarly, white clover is an important legume in temperate grazing regions for a numerous reasons such as its ability to biologically fix N, high nutritive value, increased animal DMI in mixed swards and higher animal performance in grazing systems (Chapman et al., 2017a).

It was notable in the current study that no response of PRG ploidy was observed on either daily or total milk yield. This was not entirely unexpected as previous studies have found conflicting
evidence on the effect of PRG ploidy on milk production, with some studies showing increased milk yield from cows grazing tetraploid compared to diploid swards (Castle and Watson, 1971; Lantinga and Groot, 1996; Wims et al., 2013). However, Gowen et al. (2003) reported no overall difference in milk yield between ploidy groups, but found cows grazing one tetraploid cultivar produced more milk than cows grazing the other three cultivars (one tetraploid and two diploid). This may indicate that variations between individual cultivars can be greater than between ploidies (Tubritt et al., 2018) and that the beneficial effects of individual cultivars may only be seasonally expressed (Wims et al., 2013). This is supported by the fact that in Period 3, corresponding to late lactation and autumn, cows grazing tetraploid swards produced more milk and MS than those grazing diploid swards. Recently Tubritt et al., (2020) evaluated 30 PRG cultivars and found tetraploid swards exhibited a significantly better cow ‘graze-out’ performance than diploid swards. They suggested that the proportion of tetraploid cultivars in intensively grazed swards should be optimized, however large genetic variation between cultivars was observed, suggesting the huge potential of plant breeding programmes regardless of ploidy. Also, in a commercial situation grass swards typically comprise of a mixture of tetraploid and diploid PRG cultivars so variety benefits are often diluted and plant/animal interactions are therefore absent which is a major disadvantage, especially as grass sward performance is realized through animal production.

In contrast, there was a significant increase in daily milk yield and MS yield when cows grazed PRG-white clover swards compared to PRG-only swards, regardless of ploidy (+ 596 kg milk/cow per year and + 48 kg MS/cow per year). This increase in milk production from PRG-white clover swards has been well documented in the past (Ribeiro Filho et al., 2003; Egan et al., 2018). The increase in milk production from the PRG-white clover swards was observed from May onwards in each year which is consistent with when white clover content in the sward is increasing, and is similar to other studies (Schils et al., 2000b; Woodward et al., 2001; Figure 4.2). The drivers for this increase in milk production have been; higher herbage nutritive value from PRG-white clover swards, especially in mid-season compared to PRG-only (Søegaard, 1993) and an increase in voluntary pasture DMI (Ribeiro Filho et al., 2003), with numerous studies having shown animals to selectively graze white clover over PRG (Gooding et al., 1996; Rutter et al., 2004). The higher nutritive value of the swards containing white clover was clearly observed across all four study years along with higher TDMI/cow during lactation, where cows grazing PRG-white clover swards consumed 320 kg more DM than PRG-only cows (Chapter 4). The higher DMI from PRG-white clover swards was also observed using the N-alkane
technique, with no difference in DMI in spring when sward white clover content was lowest, but significant increases were recorded in summer and autumn (+ 0.7 kg DMI in summer and + 0.9 kg DMI in autumn; Chapter 6), which corresponds to when the higher milk yields occurred and when sward white clover content was greatest. Similarly, Ribeiro Filho et al., (2003) found cows grazing swards with 40% white clover had 1.5 kg DM/cow per day increase in DMI compared to cows grazing PRG-only swards. When the production efficiencies of all four grazing treatments were examined, no significant effect of PRG ploidy was found on any of the production efficiencies reported (Chapter 6). In contrast, white clover inclusion had a significant positive effect on TDMI/100 kg BW, SCM/100 kg BW, MS/100 kg BW and MS/TDMI. When the economics underpinning the current study were computed, it showed that adding white clover to the PRG swards increased profitability by €305/ha in a fixed land area scenario with a milk price of 29c/l across cow genotype. This is an important message for pasture-based farmers as the additional costs of including white clover in PRG swards hasn’t been quantified before, particularly with additional spring feeding, bloat oil use and labour being considered. This study showed the additional costs are far outweighed by the benefits gained from additional milk production from cows grazing white clover swards. Also, the additional cost associated with an increased reseeding frequency was examined to predict a long term cost of PRG-white clover systems. This assumption is based on the observed drop in white clover content (reducing from 36% in year 1 to 14% in year four; Chapter 4). When the cost of a five year reseeding cycle was modelled (compared to ten year for PRG-only swards), this significantly increased costs (+ €181/ha), despite this, net profit was still greater for PRG-white clover swards (+ €252/ha) compared to PRG-only swards. This is a key finding as it makes it clear that if farms are to gain the financial benefits of including white clover in their reseeds, they must be prepared to commit to this more frequent reseeding cycle. Unfortunately, when finances are limited on farm, for example in a low milk price year, financial investments such as reseeding are usually avoided. The economic analysis from this thesis clearly shows that this would not be a prudent financial decision and so the evidence from the current study will be invaluable in demonstrating the benefits of investment decisions to farmers. This thesis highlights the huge potential for the use of white clover in grazing swards to increase farm productivity and profitability, while only marginally increasing costs.
8.2 Cow Genotype

Current breeding strategies in dairy herds now place greater emphasis on functional traits (mainly reproduction and health) as opposed to the more traditional selection for milk yields and animal conformation. Breeding strategies which focus on high milk production have been previously linked with a decline in animal fertility (Lucy, 2001; Dillon et al., 2003), but fortunately this decline has been recently halted through more emphasis on functional traits (Miglior et al., 2017; Cole and VanRaden, 2018; Lucy, 2019). In spring-calving, pasture-based systems the focus on functional traits is very important as compact calving is required in spring (to maximise milk production from grazed pasture) along with robust animals (Friggens et al., 2017) in order to produce milk efficiently from pasture (Shalloo et al., 2014). The current study found the performance of all 3 genotypes (HF, JEX and 3WAY) to be excellent, particularly in terms of reproductive performance (86% six-week pregnancy rate and 94% overall pregnancy rate on average), which was well above national average statistics for Ireland. This shows that while there are still improvements to be made to the national herd, the targets set for spring-calving pasture-based herds are achievable at farm-level (with good management and high genetic merit cows), regardless of genotype. However, the lack of any significant difference between the cow genotypes for reproductive performance is somewhat surprising as previous research has shown crossbred cows, and JEX in particular, to have superior reproductive performance to HF (Prendiville et al., 2011a; Vance et al., 2013). This unexpected result may be attributed to the greater emphases that are now being placed on functional traits over the past 20 years (Lucy et al., 2019). There is clear evidence of the benefits of a targeted strategy for a herd breeding programme along with the development and use of the EBI to deliver on progressive improvements (O’Sullivan et al., 2018; O’Sullivan et al., 2019). Norwegian Red was chosen as the third breed in the current study due to the findings of Walsh et al. (2008) who concluded they were most suited in a seasonal pasture-based milk production system with a two-way crossbreeding program when compared to Montbéliarde and Normande. A 3-way rotational breeding system has also been hypothesised to increase profitability for pasture-based systems in New Zealand and has the added benefits of maximising heterosis and possibly adding ‘new’ traits from a third breed (Lopez-Villalobos et al., 2000). However, very few studies have evaluated the effect of 3-way rotational crossing on animal productivity and none have used the same combination of breeds used in this study. The current study showed no additional benefit from using the 3WAY genotype compared to the more conventional F1 JEX in terms of production, reproductive performance or profitability. This may indicate a 3-way rotational
breeding system is not the best option in crossbred herds, and other options should be investigated to fill this knowledge gap. Although the excellent reproductive performance from the HF cows in the current study results are in contrast with previous studies, my thesis corroborates more recent research that has shown improvements in the reproductive performance of HF in Ireland (O’Sullivan et al., 2018; ICBFa, 2019). This suggests that when herd reproductive performance is already at a high level, the benefits of crossbreeding in terms of fertility may be negligible. Milk solids yield per cow was also similar between all three genotypes (460, 469 and 453 for HF, JEX and 3WAY, respectively), showing little benefit for crossbreeding in terms of milk solids production. However when milk solids efficiency was examined in terms of MS output per kg BW, both crossbreds outperformed HF with the JEX cows being the most efficient (0.98 kg MS/kg BW), followed by 3WAY (0.91 kg MS/kg BW), and HF (0.87 kg MS/kg BW). These results confirm previous findings that the basis of the difference in production efficiency can be attributed to differences in BW, grazing behaviour (Prendiville et al., 2010; Vance et al., 2012) and gastrointestinal tract weight (Beecher et al., 2014) specifically associated with the Jersey breed. Total DMI per kg BW was also shown to differ between genotypes with the JEX and 3WAY (3.63 and 3.45 kg) having higher TDMI/100 kg BW compared to HF (3.36 kg; Chapter 6).

The DMI of the three genotypes was also investigated along with production efficiencies. The influence of animal genotype on DMI in pasture-based systems not only occurs through the animals’ ability to consume greater quantities of pasture, but also through the capacity of the animal to calve annually at a time that facilitates the maximum amount of grazed herbage to be incorporated in that animal’s diet (Dillon, 2007). Total DMI and PDMI differed significantly between genotypes in this study with HF having the highest PDMI (16.5 kg/cow), followed by JEX (16.2 kg/cow) and 3WAY (15.9 kg/cow). These results are similar to Prendiville et al. (2009) who found DMI of 16.9 kg/cow per day with HF and 16.2 kg/cow per day with JEX cows. Production efficiencies were also investigated, with JEX cows in this study having a higher DMI/100 kg BW compared to HF cows (3.63 and 3.39 kg of DM, respectively), which is similar to results observed by Gonzalez-Verdugo et al. (2005) and Prendiville et al. (2009). Very few studies have examined DMI or production efficiencies for any 3-way rotation breeds, Shonka-Martin et al., (2018) recently compared a rotational crossbred of Montbéliarde x Viking Red x Holstein with Holstein cows for DMI. They found lower DMI from their three-way crossbred compared to HF cows with similar MS production and BW.
Finally the economics underpinning the current study were used to investigate the effect of dairy cow genotype (HF, JEX and 3WAY) on profitability under differing scenarios 1) where land area was fixed (reflective of the situation on most Irish farms) and 2) where cow numbers were fixed (which could be reflective of potential future restrictions at farm level), across differing milk prices and calf values. In the fixed land scenario with milk price of 29c/l, profitability was highest for JEX (€2,606/ha), followed by 3WAY (€2,492/ha) and HF (€2,468). As part of the sensitivity analysis, the calf price difference was increased by + €30 or + €60 for both HF and 3WAY calves compared to JEX calves, to reflect the lower demand for JEX bull calves. However, both crossbred cows were more profitable than HF cows regardless of calf value, as they can be stocked higher than HF cows due to their lower BW and energy requirement. Finally, in the fixed cow scenario JEX were the most profitable (€2,489/ha), followed by HF (€2,428/ha) and 3WAY (€2,363/ha), mainly due to their high value milk and high MS production. This thesis highlights the suitability of all three genotypes to spring-calving, pasture-based systems; however production efficiencies were higher from both crossbred cows (JEX and 3WAY). Also as JEX and 3WAY cows had lower energy maintenance requirements they can be stocked higher, which is valuable in land limited situations.

8.3 Future Work

This thesis has demonstrated the benefits of incorporating white clover into pasture-based systems by not only increasing herbage production but also increasing milk production per cow and per ha. However, while completing this thesis a number of questions have been raised that warrant further research. On a farm level the major limiting factors for PRG-white clover swards include; bloat risk, lower over-winter growth and the long term persistence of white clover in PRG swards. Bloat risk and reduced pasture availability in the spring from PRG-white clover swards remains the primary deterents for many farmers to incorporate white clover into their grazing system. Bloat risk can be managed when conditions are dangerous by including bloat oil in water systems and also restricting cows to 12 hour grazing allocations which prevents cows from solely selecting white clover in the sward. This requires a high level of grassland management with pre-grazing covers being accurate to correctly allocate herbage. Further strategies could be investigated such as the use of oils or condensed tannins in meal as a bloat preventative or a plant breeding programme for white clover varieties with a higher condensed
tannin content. However this study showed very low levels of bloat incidence throughout the four years despite high WC levels, demonstrating how invaluable grazing management practices are for bloat prevention. A combination of identifying high bloat risk paddocks (>40% WC content, wet weather, WC not yet flowered etc.) and then restricting grazing allocation or including bloat oil in drinking water proved to be the best strategy and can easily be incorporated at farm level.

Autumn grazing management has the potential to limit loss of herbage over winter by grazing high clover content paddocks last in the grazing season, thereby limiting the amount of herbage that can be potentially lost through senescence in cold conditions. This would allow a bank of higher PRG swards to build up over winter as they would be closed first in the autumn rotation planner. Further research should be conducted on autumn and spring grazing management to get the most benefits from white clover swards, particularly when a milk production benefit would be seen. Grazing strategies that encourage the persistence of WC in swards should also be investigated as previous studies have mainly focused on fertiliser application and not grazing management. The long term persistence of white clover can also be a deterrent to farmers as the benefits of white clover may last for five years or less. Strategies to maintain optimum sward white clover content should also be investigated, such as different over-sowing strategies and methodologies, reseeding practices to ensure good clover establishment and fertiliser strategies to maintain sward white clover content. A number of paddocks used in the experiment for this thesis are still maintaining a significant amount of white clover, which would be a seven year old sward now. These paddocks could be studied now to see if there is any correlation between management strategies in the past and current white clover content. Another interesting aspect would be to examine the N-use efficiency from this study from an environmental perspective and whether the additional herbage production from the white clover swards can be attributed to BNF. This would be particularly interesting to examine on a paddock basis where growth rates and white clover contents differed throughout each season and year. A limitation of the current study was that N usage and BNF were not calculated. It would have been very interesting to investigate the N pathways in both swards types to get a better understanding of N-use efficiency and also where losses occur, particularly when WC content is high and we can assume BNF is taking place which may increase herbage/milk production but could also increase N losses. This study would have greatly benefitted from an environmental impact aspect, particularly with
farming recently coming under public scrutiny for GHG contributions and WC now being compulsory for all new reseeds on farms that are part of the derogation scheme from 2020. This new derogation rule should encourage WC use on farms while potentially reducing artificial N application, without having a negative impact on herbage or animal production levels.

The results of this thesis also warrant further investigation into the effect of cow genotype on farm productivity and profitability. This thesis has shown the benefits of crossbred cows compared to HF are not as large as previously reported, in particular with reproductive performance. This is attributed to increased selection for functional traits in breeding strategies; however, there are still benefits to be gained with crossbreeding from an efficiency and economic point of view within pasture-based systems. The improvements made in the HF genotype in this study is a testament to the impact of a good breeding strategy which suits your system, and also shows the impact EBI use can have to allow you to continually improve your herd by selecting traits most important to your system. It would to interesting to investigate the survival of each genotype in a herd scenario and classify the reasons for culling which could then be targeted in any new breeding strategy. Each genotype could potentially require its own breeding strategy based on what trait they are lacking or limited in. This thesis also showed that while the 3WAY breed is suitable for pasture-based systems, they didn’t add any additional benefit compared to JEX or HF. Therefore in a 3-way rotational crossbreeding system, perhaps Norwegian Red is not the most beneficial breed to introduce and other breeds could be considered. Also, perhaps a two-way backcrossing system is a better option for farms and should be investigated further with comparisons to their F1 dam’s performance. The use of sexed semen in the dairy herd could also be utilized further in the future which would allow a proportion of the dairy herd to be bred to a beef sire to increase calf sale values. This opportunity would require a further analysis of which dairy cow genotype is best suited to breeding a beef animal in terms of gestation length and calving difficulty for the dairy farmer, and growth rates and carcass quality for the beef farmer.
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