RUNNING TITLE: GRASS SILAGE IN NORTHERN IRELAND

Grass silage composition and nutritive value on Northern Ireland farms between 1998 and 2017

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ABSTRACT

Grass silage is the predominant conserved forage offered to ruminant livestock within Northern Ireland (NI) when housed. This study involved the analysis of a dataset (n = 76,452 samples) comprising silage samples from commercial farms, analysed by the Agri-Food and Biosciences Institute (AFBI) between 1998 and 2017. The effects of harvest number (1, 2 or 3) and year were examined. Most of the differences between harvests 1 – 3 were significant although these differences were of little biological significance. Silage crude protein (CP) increased from harvests 1 to 3, while ammonia N concentration was higher in 3^{rd} harvests. Acid detergent fibre (ADF) and neutral detergent fibre (NDF) concentrations decreased from harvest 1 to 3, while dry matter (DM) digestibility and D-value (% DM) were higher in 1^{st} compared to 2^{nd} harvest. Across the twenty year period silage DM and water soluble carbohydrate concentrations increased, while ADF and NDF concentrations decreased. Crude protein concentration did not change over time. There was no significant improvement in silage digestibility. While silage intake potential for dairy cows increased by approximately 8% (from 88.8 to 96.1 g kg $W^{0.75}$, meaned across all harvests), silage intake potential for beef cattle increased only within harvest 1. Despite overall increases in silage DM concentration, silage digestibility parameters did not show any significant improvement over the twenty year period, highlighting the need for a renewed focus on improving silage nutritive value.

Key words: silage composition, digestibility, intake potential, commercial farms

INTRODUCTION

The ruminant livestock sector in Northern Ireland (NI) is largely grassland based, with 96% of all agricultural land area classified as grassland (DAERA, 2018). Ruminant livestock traditionally graze outdoors from March/April until September/October, and are housed and offered predominantly grass silage based diets for the remainder of the year. However, in recent years there has been an increase in the number of NI farms where livestock, especially dairy cows, are either completely housed all year, or housed at night for extended periods throughout the year. This follows the trend observed within Great Britain (March et al., 2014). Given the small area of maize grown for silage in NI, grass silage looks set to remain the predominant conserved forage for the ruminant livestock sector, which is reflected in the fact that grass silage was produced on 37% (298 480 ha) of the total grassland area in 2017 (DAERA, 2018).

Many factors affect grass silage composition and nutritive value, including sward composition, stage of maturity, weather conditions, soil type, harvest date, chop length, additive use, speed of silo filling and degree of compaction, type of cover, ammonia and fibre concentration, and feed-out rate post opening (Frame & Laidlaw, 2011). Grass silage is normally assessed by a combination of its chemical composition, fermentation characteristics and nutritive value, and 'silage quality' has a direct impact on subsequent animal performance. In a review, Keady et al. (2013) reported that each 10 g kg^{-1} increase in silage digestible organic matter in the dry matter (DOMD or D-value), increased silage dry matter intake (DMI) and milk yield of lactating dairy cows by 0.22 kg day^{-1} and 0.33 kg day^{-1}, respectively, while carcass gain in beef cattle and finishing lambs increased by 23.8 g day^{-1} and 9.3 g day^{-1}, respectively. Furthermore, Steen et al. (1998) identified that silage intake is closely related to factors which influence the extent of digestion, and the rate of passage of material through the animal, as indicated by the strong relationships with in vivo apparent digestibility, rumen degradability, fibre concentration and N fractions of the silage.

Changes in the composition and nutritive value of grass silage produced on NI farms have been reviewed periodically over the last 50 years. For example, Jackson et al. (1974) and Unsworth (1981) summarised the analyses of silages produced between 1967 – 1972 and between 1973 – 1979, respectively. Jackson et al. (1974) and Unsworth (1981) reported that there were no consistent trends in silage dry matter (DM) concentration, fibre concentration and digestibility. There was however a marked increase in silage crude protein (CP) concentration during the period between 1973-1979, despite similar amounts of fertiliser nitrogen (N) use during that period, with Unsworth (1981) explaining this trend by a general shift to earlier harvesting dates and the adoption of more frequent harvesting regimes during those years. Unsworth (1981) also suggested that differences in chemical composition of silages between years could be ascribed to variations in the climatic conditions, and it should be noted that the periods covered within each of these reviews were relatively short, typically 5 - 7 years.

Significant changes in silage making practices and technologies have taken place since silage analyses were last reviewed in NI, with some of these changes reviewed by Wilkinson & Rinne (2018). Consequently, silages produced today might be expected to differ in composition and nutritive value compared to the silages reviewed by Unsworth (1981), and indeed to silages produced two decades ago. Furthermore silage analytical techniques have changed considerably over the years, with the use of 'wet chemistry' now largely superceded by Near Infrared Reflectance Spectroscopy (NIRS) which is routinely used to predict silage composition, fermentation characteristics, digestibility and intake potential (Park et al., 1998).

The current study examines changes in composition and nutritive of grass silages produced on NI farms from 1998 to 2017.

MATERIALS AND METHODS

During the 20 year period between 1998 and 2017, a total of 78,958 grass silage samples from commercial farms across NI were submitted to the Hillsborough Feeding Information Service (HFIS) laboratory at AFBI Hillsborough. Each silage sample had information available describing year of harvest (1998–2017) and harvest number (1, 2, 3, 4 and 5). Fresh silage samples had been scanned within 24 hours of receipt using NIRS, as described by Park et al. (1998). The NIRS spectra generated were then used to predict the chemical composition (DM, CP, pH, neutral detergent fibre [NDF], acid detergent fibre [ADF], water soluble carbohydrate [WSC], and ash), fermentation characteristics (lactic acid [LA], volatile fatty acids [VFA] and ammonia nitrogen [NH_3-N]) and nutritive values of these silages (DM digestibility [DMD], D-value, dairy cow intake potential and beef cattle intake potential), using a series of prediction equations. These prediction equations were developed at AFBI, with the equations used to predict nutritive value derived following an in vivo evaluation of 136 grass silages of differing qualities obtained from local farms (Steen et al., 1998).

Of the 78,958 silage samples available within the data base, 2507 results were excluded for the following reasons: unknown harvest number (n = 2159); fourth and fifth harvest (n = 257); DM concentrations greater than 60% (n = 90); and ammonia N concentration greater than 1000g kg^{-1} N (n=1). This left a total of 76,452 silage samples for inclusion within the analysis. The number of samples in each harvest year for harvests 1, 2 and 3 are shown in Table 1.

Total quantities of fertilizer nitrogen delivered in NI for agriculture and horticulture use over the period 1998 - 2017 was obtained from https://www.daera-ni.gov.uk/publications/fertiliser-statistics-2009-2019.

Silage analysis variables over the 20 year period were examined for linear effects using an unbalanced ANOVA with a factorial arrangement of Year and Harvest fitted as the treatment factors. For significant effects ($P<0.05$) the Fisher's LSD test was used to assess the pairwise differences between individual levels of that effect. In addition, simple linear regression analysis was conducted within each harvest to examine if silage analysis variables changed over the 20 year period. All data were analysed using GenStat (16th edition; VSN International Limited, Oxford, UK).

RESULTS AND DISCUSSION

The overall increase in the number of silage samples submitted to AFBI for analysis between 1998 and 2017 (Table 1) is likely to reflect an increasing level of confidence that farmers had in the service, and a general move by farmers to more closely align rations offered to silage analysis results. The decline in the number of samples submitted after 2013 was largely due to the increasing availability of similar analytical services within the commercial sector. The large number of first harvest samples analysed, relative to second harvest, demonstrates the importance placed by farmers on first harvest, with this likely to be the forage offered to the most productive livestock on farms over the winter. The small number of third harvest samples analysed is likely to reflect the fact that many farmers (especially dry stock farmers) still operate one or two harvest systems, while there is anecdotal evidence that third harvests are normally offered to livestock with lower nutritional requirements.

Comparison of 1st, 2nd and 3rd harvests

When examining the effects of harvest number on silage composition and nutritive value (Table 2), it is important to recognise that the number of 3rd harvest samples analysed was relatively small, and that farmers submitting these samples may represent a 'self-selecting' group who may make third cut silage with an improved composition and nutritive value than the average farmer. First harvest had a higher DM concentration (260 g kg^{-1}, *$p<0.001$*) than both 2nd and 3rd harvests (Table 2). Nevertheless, from a practical point of view, differences in DM concentration between harvests were surprisingly small. The increase in silage CP concentration from 1st harvest through to 3rd harvest (118, 121 and 140 g kg^{-1} DM, respectively: *$p<0.001$*) is comparable to the CP concentrations reported by Termonen et al. (2020), and likely reflects the increasingly vegetative stage of herbage harvested as the season progresses, as indicated by the decreasing NDF and ADF concentration of the silages. It is suggested that increasing ash concentrations with later harvests (*$p<0.001$*) may reflect increasing soil contamination of crops or soil contamination being less 'diluted' within lighter crops later in the season. Although the NH_3-N concentrations in 3rd harvests were significantly higher than in 1st and 2nd harvests (107 g kg^{-1} total N, compared with 103 and 102 g kg^{-1} total N, respectively) the differences are unlikely to be of biological importance. However this small difference may suggest increased proteolysis of plant protein by plant and microbial enzymes in the 3rd harvest. The high lactic acid concentrations observed across all harvests indicate lactic acid based fermentations dominate within the data set, with concentrations highest in 3rd harvests. In contrast, volatile fatty acids (VFA) concentrations were higher at first harvest (*$p<0.001$*: 27.2 g kg^{-1} DM) than at either of harvests 2 or 3 (23.3 and 22.9 g kg^{-1} DM, respectively) which may reflect higher concentrations of acetic acid (AHDB, 2012). Differences in pH at harvests 1 and 2 reflect differences in lactic acid concentrations at these two harvests. Dry matter digestibility and D-value (% DM) were higher in 1st compared to 2nd harvest although this difference arose despite only small differences in fibre concentration between these two harvests. Nevertheless, the higher digestibility of 3rd compared to 2nd harvest is reflected in lower fibre concentrations with the latter, in agreement with the findings of Thorvaldsson et al. (2007), who stated that this is due to low average temperatures and low radiation during the late summer period in northern climate zones. Both dairy cow and beef cattle intake potential followed similar trends to digestibility, which is not surprising as the latter a key driver of forage intake (Steen et al., 1998). Huuskonen and Pesonen (2017) found second harvest to give lower DM and energy intakes with finishing bulls, than first or third harvest which they concluded was due to lower digestibility. In general, while there were many significant differences between silages analysed from 1st, 2nd and 3rd harvests, many of the differences observed between harvests were numerically small and of limited biological importance

Changes in silage analyses between 1998 and 2017

Chemical composition Within each of the three harvests, silage DM concentration increased ($p<0.001$) over the 20 year period (Figure 1a), and while there was considerable year-to-year variation in silage DM concentration, the mean rates of increase in DM were 3.29, 2.02 and 2.22 g year^{-1} for harvests 1, 2 and 3, respectively. This appears to be part of a longer term trend, with Figure 2a showing that mean silage DM concentration during the first 10 years of this survey period (1998 – 2007) was higher than the mean DM reported by Unsworth (1981) between 1973 – 1979 and by Jackson et al. (1974) between 1967 – 1972. This is likely due to the change in silage production systems over time, including the move away from direct cut systems to pre-mowing followed by a period of field wilting (Wright, 1997), the use of mechanical treatments such as conditioning, and spreading the cut swath in good weather conditions to further enhance wilting of mown grass crop (Frame and Laidlaw, 2011). The use of mower conditioners, mowers which spread the cut sward over most of the mown area, grass tedders, and grass rakes which allow mown herbage to be raked up quickly, have all facilitated the adoption of rapid wilting techniques, thus allowing farmers to maximize the opportunity offered by short periods of good weather (Wright, 1997). While ensiling herbage with higher DM concentrations will reduce effluent losses and improve fermentation characteristics, silage made using rapid wilting techniques has been shown to have a higher intake and to improve animal performance (Yan et al., 1996 & 1998). Changes in laboratory methods for determining silage DM concentration (Porter et al., 1984), from oven DM to alcohol corrected DM, will also have contributed to the increasing DM concentration observed between the current data set and the earlier data of Jackson et al. (1974).

There was no significant change in silage CP concentration over the 20 year period examined within the study, although third harvests had a consistently higher CP than either 1st or 2nd harvests each year (Figure 1b). However, mean protein concentrations over the twenty year period covered by the data set were actually lower than those in samples analysed between 1967 – 1972 (mean of 135 g kg^{-1} DM) and 1973 – 1979 (mean of 144 g kg^{-1} DM)(Figure 2b). Part of this decrease may be due to CP concentrations being expressed on an alcohol corrected DM basis in the current dataset, and on an oven DM basis in earlier datasets. However, herbage CP concentration is largely determined by the maturity of the herbage at harvest, and by applications of both organic and inorganic N. Total fertilizer N purchases between 1979-1997 were 101 000 tonnes/year, compared with an average value of 84 800 tonnes/year between 1998-2017 (DAERA 2020). Collectively these changes likely explain the decline in silage protein concentrations between the earlier surveys and the present survey. Within the timeframe of the current dataset, the introduction of the Nitrates Action Programme (NAP) in NI (DAERA, 2007), as required by the EU Nitrates Directive, led to a reduction in fertilizer N applications to grassland. This is highlighted in Figure 3, which shows the total quantities of fertilizer N delivered in NI between 1998 and 2017 (DAERA, 2020). While there was much variation in silage crude protein concentrations from year to year, there was a trend, especially in the latter part of the data set, for silage CP concentrations to follow the trends in fertilizer N deliveries. The impact of the reduction in silage protein concentrations, relative to historical concentrations, has mixed implications for ruminant nutrition. For example, protein is an essential nutrient for livestock production, and lower protein concentrations in silages may necessitate increased concentrations of protein supplementation via concentrates. However, silage protein is readily degradable in the rumen (Termonen et al., 2020), and if the ammonia arising from its breakdown is not captured efficiently by rumen microbes, much will be excreted in manure. Thus lower protein silages may actually result in improved N use efficiency in ruminants, albeit with additional costs associated with concentrate purchases.

Both ADF and NDF concentrations in the silage samples analysed showed a significant decline over the 20 year study period, as shown in Figures 1c and 1d, respectively. The likely explanation for this is a move by farmers to harvest herbage either earlier, or more frequently so as to increase silage digestibility, as demonstrated by Kuoppala et al. (2008) and Randby et al. (2012).

The WSC concentration of silage samples increased ($p>0.001$) over the 20 year period within all harvests (Figure 1e). This increase in residual WSC concentrations is likely to reflect a less extensive fermentation as a consequence of the increase in DM concentration of the herbage ensiled, as discussed in McDonald et al. (1981). While higher residual WSC concentrations may provide a rapidly available energy source for rumen microbes, they can also leave the silage more susceptible to aerobic deterioration following silo opening, with an associated loss of nutritive value (Conaghan et al., 2012).

While ash is derived from the inorganic constituents of silage, it can also be indicative of soil contamination. High ash concentrations as a result of soil contamination (> 100 g kg^{-1} DM) can lead to a poor fermentation, reduced intakes and poorer animal performance (AHDB, 2012). Ash concentrations in NI silages have remained relatively unchanged over the 20 year period, with concentrations generally within the range of 75 – 90 g kg^{-1} DM (Figure 1f). There is anecdotal evidence that grass rakes, which have been increasingly used by contractors over the 20 year experimental period to 'row up' grass for lifting, can increase soil contamination. While this may be an issue if rakes are set too 'low', the absence of an increase in ash concentrations suggests that this has not been a significant issue.

Fermentation characteristics Lactic acid concentrations declined over the 20 year period in each of harvests 1 ($p<0.05$), 2 ($p<0.05$) and 3 ($p<0.001$), with total VFA concentrations also declining ($p<0.001$) (Figure 4a and b, respectively). These effects suggest a shift towards more restricted fermentations within NI silages, in line with the increasing residual WSC concentrations observed, and this is likely a consequence of the increasing DM concentration of the herbage ensiled. In view of the trends in lactic acid and VFA concentrations, it was surprising that silage pH did not change ($p>0.05$) over the 20 year period (Figure 4c). In higher DM silages with a restricted fermentation, Coblentz & Akins (2018) reported that lower concentrations of fermentation acids were associated with a higher final pH. It is of course true that achieving a low pH is less critical with higher DM silages.

While NH_3-N concentrations (as a proportion of total N), tended to increase over the 20 year period, this effect was only significant ($p<0.001$) for 3rd harvests (Figure 4d). Increasing NH_3-N concentrations suggest increasing plant proteolysis, with DM and pH being two of the main factors affecting this process in silage (Slottner et al., 2006). However, proteolysis tends to be more extensive in wetter silages, and given the increasing DM concentrations observed across the twenty year period in this study, the trends in ammonia N concentrations may be as a result of a slower fall in pH with higher DM silage, with an associated increase in proteolysis (Muck et al., 1996).

Intake potential and digestibility Despite the improving trends in DMD (Figure 5a) and D-value (Figure 5b) in 1st harvests, these effects were not significant. Furthermore the DMD and D-value of 2nd and 3rd harvests tended to decrease over time, although this was only significant with D-value of 3rd harvests ($p<0.05$). Given the significant reductions in silage ADF and NDF concentrations in all harvests over the 20 year period, an increase in silage digestibility might have been expected, albeit digestibility is also affected by CP concentration which did not change over the same period. The absence of any measurable improvement in silage digestibility is of significant concern given that digestibility is considered to be one of the most important determinants of silage feeding value and performance of animals offered grass silage (Steen, 1992;

Scollan et al., 2001; Keady et al., 2013). Silage digestibility is affected by the composition of the herbage ensiled and by plant maturity at harvest. While plant breeding has resulted in incremental improvements in both yield and digestibility of perennial ryegrass varieties in recent decades, the low rate of reseeding in NI of approximately 3.5% of the NI grassland area per year (DAERA, 2018) has likely limited opportunities to benefit from these new varieties. While most farmers recognize that mowing herbage at a less mature stage will result in silage with a higher digestibility, many factors prevent this from happening, including adverse weather and/or ground conditions, high herbage nitrate concentrations, and unavailability of contractors (Ferris et al., 2019). In addition, the majority of contractors still charge farmers on an area basis, and not on the basis of herbage yield, thus incentivising farmers to delay harvesting to increase yields, and as such reduce contractor charges per tonne of herbage ensiled (Ferris et al., 2019). Nevertheless, the survey by Ferris et al. (2019) indicated that for farmers who believed silage nutritive value had improved on their farms over the previous decade, 37% attributed this to ‘earlier/more frequent harvesting of grass’, while 22% attributed this to ‘reseeding/improved varieties/weed control’.

The calculated intake potential of silages for dairy cows increased significantly ($p<0.001$: Figure 5c) within all three harvests between 1998 and 2017, by approximately 8%. In contrast, the calculated intake potential of silages for beef cattle (Figure 5d) increased only within 1st harvests ($p<0.05$). That different intake responses are derived from the same data set is due to the adoption of different intake predictions for lactating dairy cows and growing beef cattle. For example, the intake potential for beef cattle is derived by placing weightings on a number of parameters derived from the NIRS analysis of silage, including DM, CP, NH_3-N, and DOMD (Steen et al., 1998). In contrast, the intake potential of silage for dairy cows is derived from models which include a correction for supplementary concentrates, a milk yield adjustment factor to standardize milk yields, with these models converting a predicted intake potential for beef cattle to one for dairy cows (McNamee et al., 2005). In the case of dairy cow intake potential, the increase in silage DM concentration, and the reduction in fibre concentration over the 20 year period are two of the key drivers for the increase in intake potential observed, which is in agreement with the findings of Huhtanen (2007), and likely a result of earlier harvesting and a move toward rapid wilting of crops pre-ensiling.

CONCLUSION

This unique database allows for a long term examination of trends in the composition and nutritive value of grass silage produced on NI dairy farms, both between harvests and over a 20 year time period. While crude protein increased from harvest 1 to 3, and fibre concentrations decreased, in general, most of the differences between harvests, although significant, were small and of little practical importance. Over the 20 year period, silage DM concentration increased, most likely reflecting the adoption of rapid wilting techniques, with this accompanied by higher residual sugar concentrations, and decreasing lactic acid concentrations. While fibre concentrations decreased over the 20 year period, this was not accompanied by an increase in silage DMD, a disappointing observation. Given that grass silage remains the predominant forage for housed ruminant livestock in NI, and the absence of significant improvements in parameters such as DMD, a renewed focus on improving silage nutritive value is required.

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REFERENCES

Agriculture and Horticulture Development Board (2012) Grass+ Factsheet 17 - Grass Silage Analysis. https://dairy.ahdb.org.uk/resources-library/technical-information/grass-management/grassplus-factsheet-17-grass-silage-analysis/.

Coblentz, W.K., & Akins, M.S. (2018) Silage review. Recent advances and future technologies for baled silages. Journal of Dairy Science 101, 4075-4092.

Conaghan, P., O'Kiely, P. & O'Mara, F. P. (2012). Possibilities of increasing the residual water-soluble carbohydrate concentration and aerobic stability of low dry-matter perennial ryegrass silage through additive and cultivar use. Grass and Forage Science, 67, 177-198.

DAERA (2007). Nitrates and Phosphorous Regulations. From https://www.daera-ni.gov.uk/sites/default/files/publications/dard/nitrates-regulations-summary-2007-2010.pdf

DAERA (2018). The Agricultural Census in Northern Ireland Results for June 2018. CAP Policy, Economics and Statistics Division. From https://www.daera-ni.gov.uk/sites/default/files/publications/daera/Agricultural%20Census%20in%20Northern%20Ireland%202017.pdf

DAERA (2020). Fertiliser Time series Data from 1979 onwards. https://www.daera-ni.gov.uk/publications/fertiliser-statistics-2009-2019

Ferris, C.P., Laidlaw, A.S., & Gordon, A.W. (2019). Silage making practices on Northern Ireland dairy farms and factors perceived by farmers to influence silage quality. In: Proceedings of the British Society of Animal Science Annual Conference 2019, p78. Edinburgh, UK.

Frame J. & Laidlaw A.S. (2011). Improved Grassland Management, New edition: Crowood Press Ltd., 353 pp.

Huhtanen, P., Rinne, M., & Nousiainen, J. (2007) Evaluation of the factors affecting silage intake of dairy cows: a revision of the relative silage dry-matter intake index. Animal, 1, 758-770. https://doi: 10.1017/S175173110773673X

Huuskonen, A. & Pesonen, M. (2017). A comparison of first-, second- and third-cut timothy silages in the diest of finishing bulls. Agricultural and Food Science, 26, 16-24.

Jackson, N., O'Neill, S.J.B. & Dawson, R.R. (1974). The composition and quality of grass silages made in Northern Ireland – An analysis of six years results (1967 – 1972). Record of Agricultural Research (Ministry of Agriculture for Northern Ireland), 18, 45 – 50.

Keady, T.W.J., Hanrahan, J.P., Marley, C.L. & Scollan, N.D. (2013). Production and utilization of ensiled forages by beef cattle, dairy cows, pregnant ewes and finishing lambs – A review. Agricultural and Food Science, 22, 70-92. https://doi.org/10.23986/afsci.6852

Kuoppala, K., Rinne, M., Nousiainen, J. & Huhtanen, P. (2008). The effect of cutting time of grass silage in primary growth and regrowth and the interactions between silage quality and concentrate level on milk production of dairy cows. Livestock Science, 116, 171-182. https://doi.org/10.1016/j.livsci.2007.10.002

McDonald, P., Edwards, R.A. & Greenhalgh, J.F.D. (1981). Animal Nutrition (3rd edition) Longman Inc., New York.

March, M.D., Haskel, M.J., Chagunda, M.G.G., Langford, F.M. and Roberts, D.J. (2014). Current trends in British dairy management regimes. Journal of Dairy Science, 97, 7985-7994. https://doi.org/10.3168/jds.2014-8265

Muck, R.E., Mertens, D.R., & Walgenbach, R.P. (1996). Proteolysis in Different Forage Silages. ASAE Paper No. 961031, American Society of Agricultural Engineers, St. Joseph, MI.Google Scholar

McNamee, B.F., Woods, V.B., Kilpatrick, D.J., Mayne, C.S., Agnew, R.E., & Gordon, F.J. (2005). The prediction of the intake potential of grass silage in the supplemented diets of lactating dairy cows. Livestock Production Science, 92, 233–240.

Park, R.S., Agnew, R.E., Gordon, F.J. & Steen, R.W.J. (1998). The use of near infrared reflectance spectroscopy (NIRS) on undried samples of grass silage to predict chemical composition and digestibility parameters. Animal Feed Science and Technology,72,155-167. https://doi.org/10.1016/S0377-8401(97)00175-2

Porter, M.G., Patterson, D.C., Steen, R.W.J., and Gordon, F.J., (1984). Determination of dry matter and gross energy of grass silage. 7th Silage Conf. Proc., Paper 45, The Queen’s University of Belfast.

Randby, A.T., Weisbjerg, M.R., Nørgaard, P. & Heringstad, B. (2012). Early lactation feed intake and milk yield responses of dairy cows offered grass silages harvested at early maturity stages. Journal of Dairy Science, 95, 304-317.

Scollan, N.D., Sargeant, A., McAllan, A.B. & Dhanoa, M.S. (2001). Protein supplementation of grass silages of differing digestibility for growing steers. Journal of Agricultural Science, Cambridge, 136, 89-98. https.//doi.org/10.1017/S002185960000856X

Steen, R.W.J. (1992). The performance of beef cattle given silages made from perennial ryegrasses of different maturity groups, cut on different dates. Grass and Forage Science, 47, 239-248. https://doi.org/10.1111/j.1365-2494.1992.tb02268.x

Steen, R.W.J., Gordon, F.J., Dawson, L.E.R., Park, R.S., Mayne, C.S., Agnew, R.E., Kilpatrick, D.J. & Porter, M.G. (1998). Factors affecting the intake of grass silage by cattle and predication of silage intake. Animal Science, 66, 115-127. https://doi.org/10.1017/S1357729800008894

Slottner, D. & Bertilsson, J. (2006) Effect of ensiling technology on protein degradation during ensilage. Animal Feed Science and Technology, 127, 101-111.

Termonen, M., Korhonen, P., Kykkanen, S., Karkonen, A., Toivakka, M., Kauppila, R. & Virkajärvi, P. (2020). Effects of nitrogen application rate on productivity, nutritive value and winter tolerance of timothy and meadow fescue cultivars. Grass and Forage Science, 75, 111-126. https://doi.org/10.1111/gfs.12461

Thorvaldsson G., Tremblay, G.F. & Kunelius, T.H. (2007). The effects of growth temperature on digestibility and fibre concentration of seven temperate grass species. Acta Agriculturae Scandanavica, Section B, Soil and Plant Science, 57, 322-328.

Unsworth, E.F. (1981) The composition of grass silages made in Northern Ireland – An analysis of seven years' results (1973 – 1979). Record of agricultural research (Ministry of Agriculture for Northern Ireland), 21, 91 – 97.

VSN International (2017). Genstat for Windows 19th Edition. VSN International, Hemel Hempstead, UK. www.Genstat.co.uk.

Wilkinson, J.M. & Rinne, M. (2018). Review article: Highlights of progress in silage conservation and future perspectives. Grass and Forage Science, 73, 40–52. https://doi.org/10.1111/gfs.12327

Wright D.A. (1997). The influence of different factors on the drying rate of silage grass and development of predictive models. Ph.D. thesis. Queens University, Belfast.

Yan T., Patterson D.C., Gordon F.J. & Porter M.G. (1996). The effects of wilting grass prior to ensiling on the response to bacterial inoculation. 1. Silage fermentation and nutrient utilisation over three harvests. Animal Science, 62, 405-417.

Yan T., Patterson D.C., Gordon F.J. & Kilpatrick D.J. (1998). Effects of bacterial inoculation of unwilted and wilted grass silages. 1. Rumen microbial activity, silage nutrient degradability and digestibility. Journal of Agricultural Science, Cambridge, 131, 103-112.

Table 1. The number of silage samples analysed by AFBI each year between 1998 and 2017, subdivided by harvest number (1^{st}, 2^{nd} and 3^{rd})

	1^{st} harvest	2^{nd} harvest	3^{rd} harvest	Annual total
1998	1478	690	60	2228
1999	1404	806	64	2274
2000	1629	881	106	2616
2001	1432	857	131	2420
2002	2925	1081	90	4096
2003	2452	1181	115	3748
2004	2496	1475	214	4185
2005	2510	1271	198	3979
2006	2299	1431	224	3954
2007	2400	1338	186	3924
2008	2644	1629	234	4507
2009	2764	939	195	4498
2010	2556	1722	285	4563
2011	2969	1730	345	5044
2012	3494	2065	424	5983
2013	2916	1851	525	5292
2014	2346	1219	356	3921
2015	1715	921	203	2839
2016	1833	1051	231	3115
2017	1934	1074	257	3266
Total	46196	25813	4443	76452

Table 2 Effect of silage harvest number (1st, 2nd and 3rd) on silage analyses in Northern Ireland between 1998 and 2017

	Harvest				
	1st harvest	2nd harvest	3rd harvest	SEM	*p*-value
Dry matter (g kg^{-1})	260^{b}	256^{a}	257^{a}	0.4	<0.001
Crude protein (g kg^{-1} DM)	118^{a}	121^{b}	140^{c}	0.1	<0.001
Neutral detergent fibre (g kg^{-1} DM)	509^{c}	503^{b}	477^{a}	0.3	<0.001
Acid detergent fibre (g kg^{-1} DM)	329^{c}	327^{b}	312^{a}	0.2	<0.001
Water soluble carbohydrate (g kg^{-1} DM)	24.1^{b}	23.7^{a}	25.2^{c}	0.11	<0.001
Ash (g kg^{-1} DM)	76.5^{a}	80.9^{b}	89.2^{c}	0.06	<0.001
NH_3-N (g kg^{-1} total N)	103^{b}	102^{a}	107^{c}	0.2	<0.001
pH	4.03^{b}	3.97^{a}	4.05^{c}	0.04	<0.001
Lactic acid (g kg^{-1} DM)	68.3^{a}	71.6^{b}	77.1^{c}	0.19	<0.001
Volatile fatty acids (g kg^{-1} DM)	27.2^{b}	23.3^{a}	22.9a	0.09	<0.001
Dry matter digestibility (% DM)	70.3^{c}	68.5^{b}	69.7^{a}	0.03	<0.001
D-value (% DM)	67.2^{c}	65.6^{a}	66.4^{b}	0.03	<0.001
Dairy intake potential (g kg^{-1} $W^{0.75}$)	94.2^{c}	91.3^{a}	93.0^{b}	0.06	<0.001
Beef intake potential (g kg^{-1} $W^{0.75}$)	78.6^{c}	74.7^{a}	76.0^{b}	0.06	<0.001

Means with the same superscript within rows do not differ significantly (p>0.05)

D-value, Digestible Organic Matter in dry matter; $W^{0.75}$, metabolic liveweight

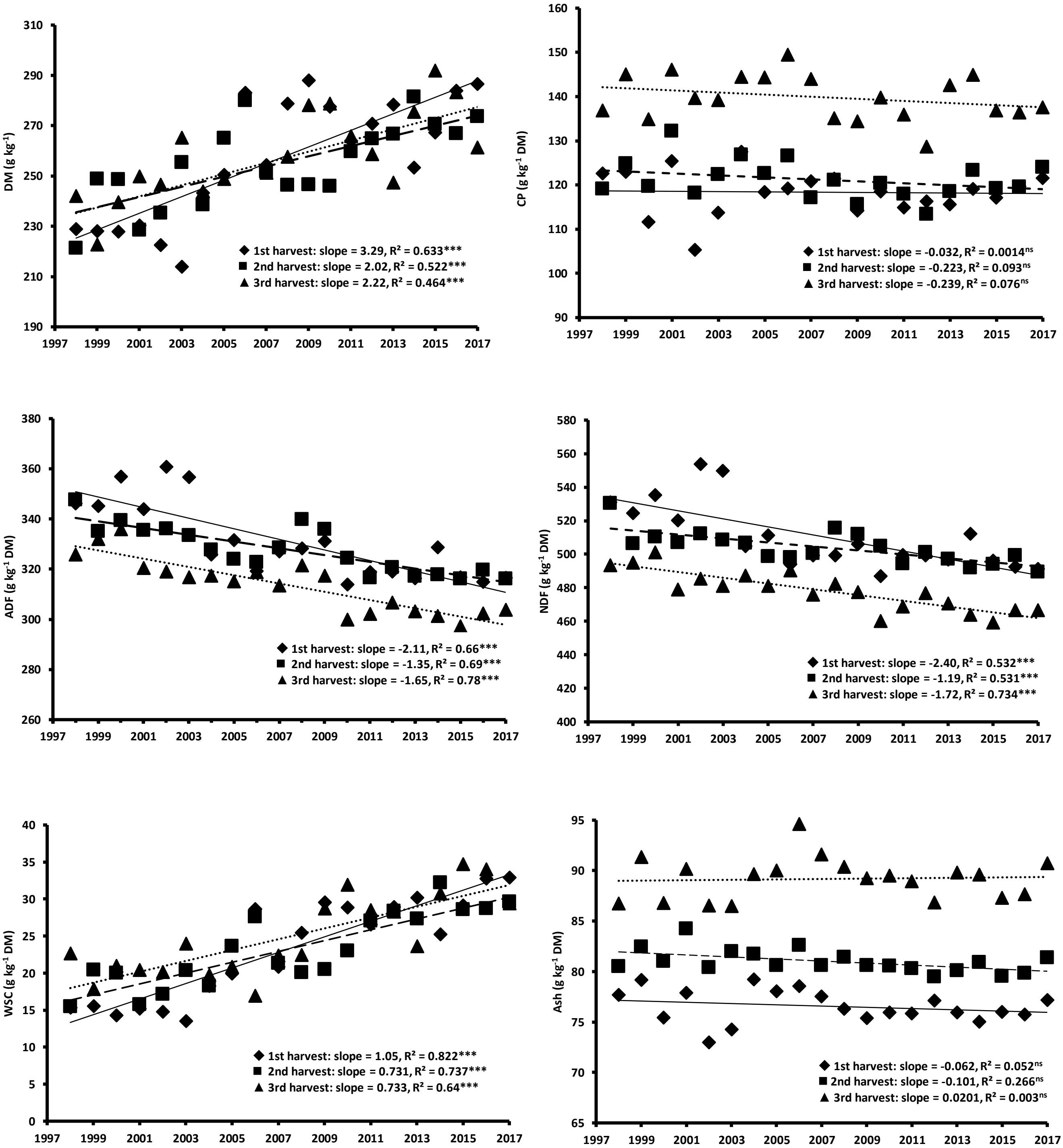


Figure 1. Changes in the (a) dry matter (DM), (b) crude protein (CP), (c) acid detergent fibre (ADF), (d) neutral detergent fibre (NDF), (e) water soluble carbohydrate (WSC) and (f) ash content of first (solid line), second (dashed line) and third harvests (dotted line) of grass silages made on Northern Ireland farms and analysed at AFBI between 1998 and 2017. Data with *, ** and *** indicate the relationship was significant at the $p<0.05$, $p<0.01$ or $p<0.001$ level, respectively, or ns = non-significant

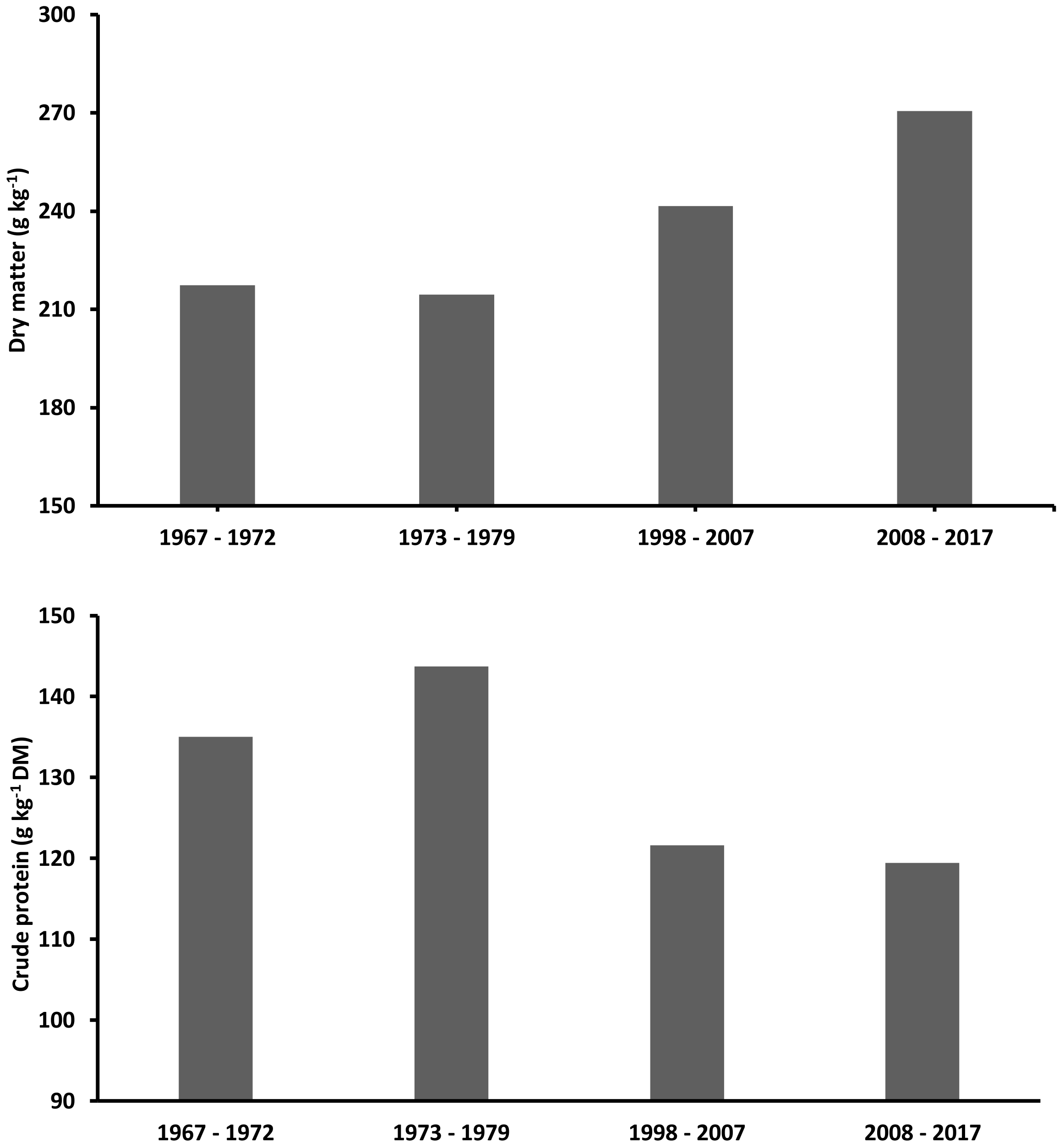


Figure 2. Long term trends in dry matter content (a) and crude protein content (b) of grass silage samples from Northern Ireland farms analysed by AFBI between 1967–1972 (Jackson *et al*., 1974), 1973-1979 (Unsworth, 1981) and 1998-2007 and 2008-2017 (current data set)

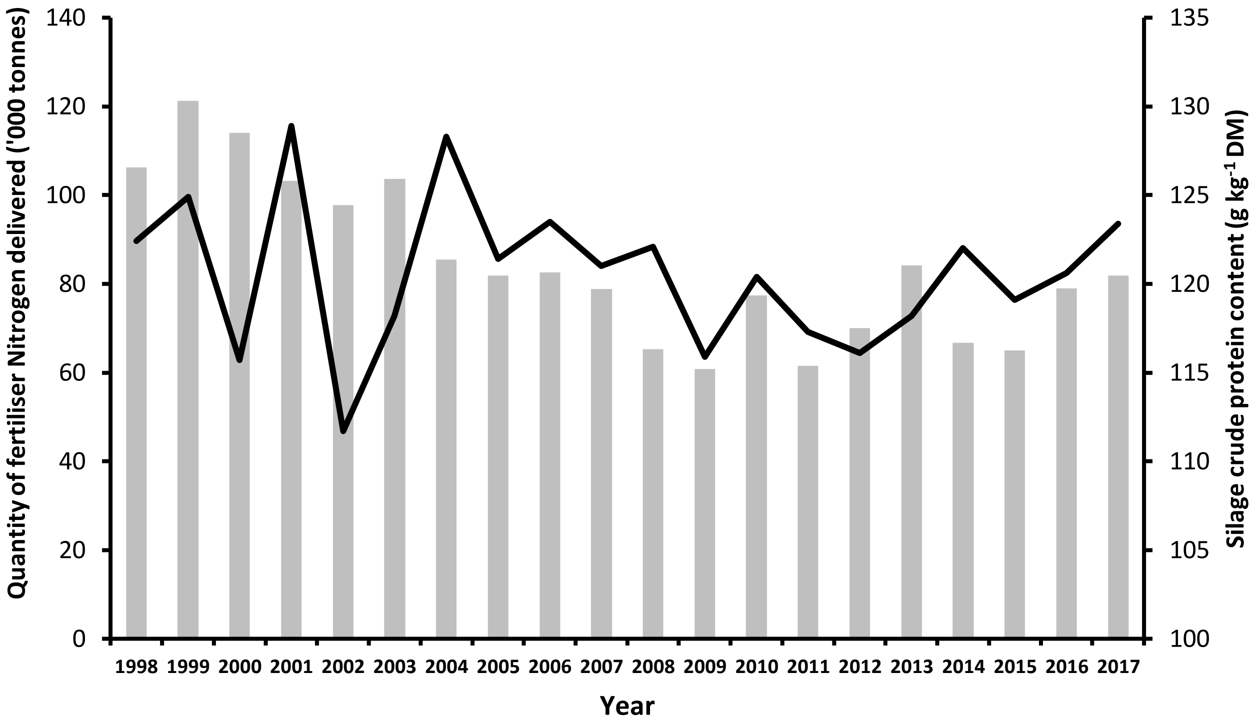
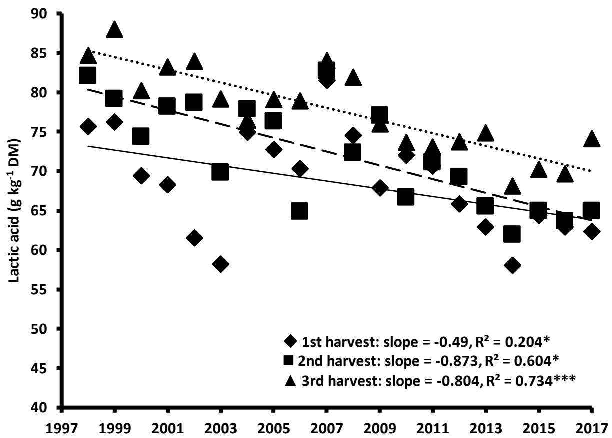
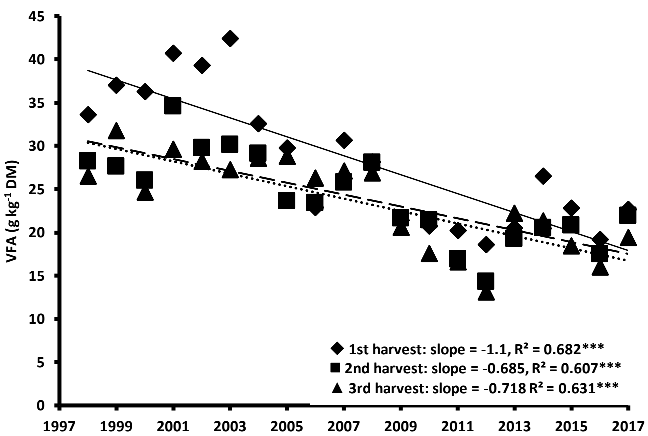
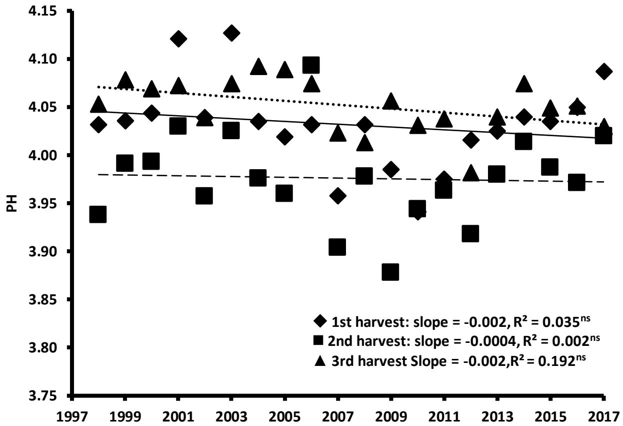


Figure 3. The total quantity of fertiliser nitrogen delivered annually in Northern Ireland between 1998 and 2017 (grey bars), and the mean crude protein content (black line) of all silage samples (harvests 1, 2 and 3) analysed by AFBI each year over the same period


Lactic acid (g kg⁻¹ DM)
90
85
80
75
70
65
60
55
50
45
40
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
1st harvest: slope = -0.49, R² = 0.204*
2nd harvest: slope = -0.873, R² = 0.604*
3rd harvest: slope = -0.804, R² = 0.734***


VFA (g kg⁻¹ DM)
45
40
35
30
25
20
15
10
5
0
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
1st harvest: slope = -1.1, R² = 0.682***
2nd harvest: slope = -0.685, R² = 0.607***
3rd harvest: slope = -0.718 R² = 0.631***



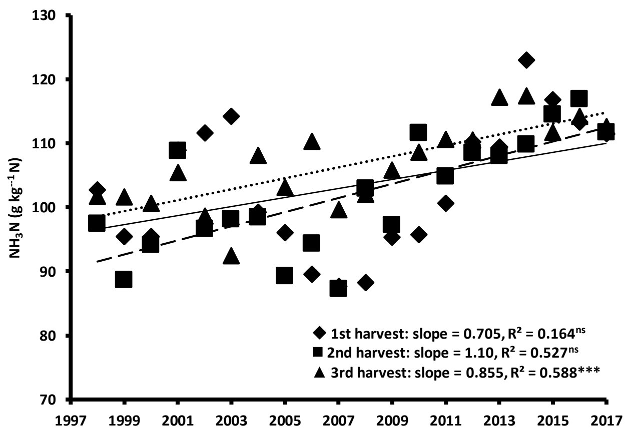
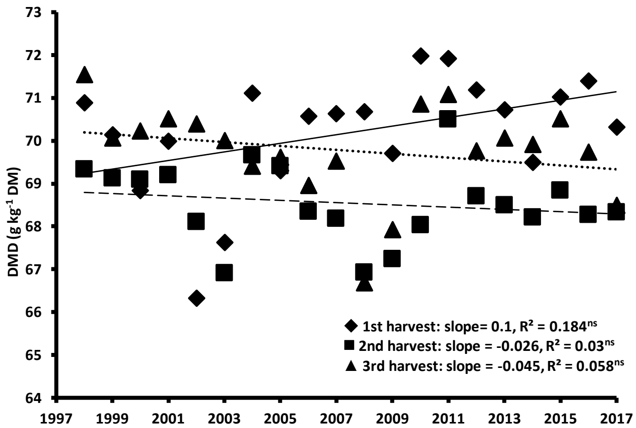
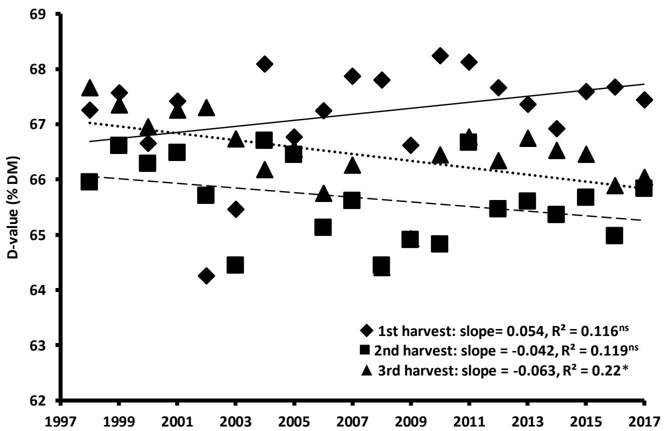


Figure 4. Changes in the (a) lactic acid, (b) volatile fatty acids (VFA), (c) pH and (d) NH_3-N content, of first (solid line), second (dashed line) and third harvests (dotted line) of grass silages made on Northern Ireland farms and analysed at AFBI between 1998 and 2017. Data with *, ** and *** indicate the relationship was significant at the p<0.05, p<0.01 or p<0.001 level, respectively, or ns = non-significant.


DMD (g kg-1 DM)
1st harvest: slope= 0.1, R² = 0.184ns
2nd harvest: slope = -0.026, R² = 0.03ns
3rd harvest: slope = -0.045, R² = 0.058ns


D-value (% DM)
1st harvest: slope= 0.054, R² = 0.116ns
2nd harvest: slope = -0.042, R² = 0.119ns
3rd harvest: slope = -0.063, R² = 0.22*

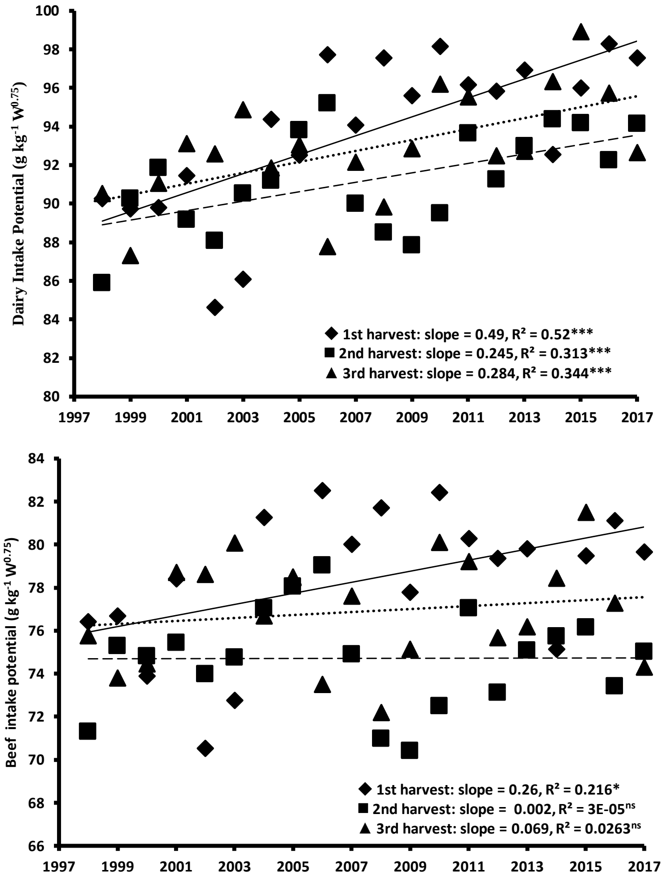


Figure 5. Changes in the (a) dry matter digestibility (DMD), (b) D-value, (c) dairy intake potential and (d) beef intake potential of first (solid line), second (dashed line) and third harvests (dotted line) of grass silages made on Northern Ireland farms and analysed at AFBI between 1998 and 2017. Data with *, ** and *** indicate the relationship was significant at the p<0.05, p <0.01 or p <0.001 level, respectively, or ns = non-significant