

Growing and feeding forage maize – a review

Research Partnership: Grasslands, Forage and Soil

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Chapter 1- Site Selection

Introduction

Maize was first domesticated in modern day Mexico about 10,000 years ago (Wang *et al.*,1999, Rebourg *et al.*,2003) and is a tropical crop. It first came to Europe during the 16th century and has established itself as an important forage and grain crop across large parts of Europe. As a tropical crop it grows best in warm climates with a longer growing season than that experienced in much of the UK, furthermore it benefits from being grown in sheltered locations with little wind (Phipps and Wilkinson,1985). Due to advances in breeding and the warming climate the area of maize grown in the UK has increased considerably in the last 20 years, for example in 1990 maize area was estimated at 33,000 Ha in England (Limagrains,2014, PDA,2014) growing to 146,000 Ha in 2010(DEFRA,2010). 196,000 Ha of maize were grown in the UK in 2013, a 24.1% increase over 2012 (DEFRA and ONS,2013). Between 1961 and 2006 average annual temperatures have increased between 1 and 1.7⁰C. The largest temperature increases have been in the South East of England with the smallest change being in Scotland (UKCIP,2013). The area of the UK in which maize is grown has spread from the favourable South of the country to more marginal areas in the West and North.

The marginal nature of maize as a UK crop makes site selection one of the most important factors to take into consideration when deciding whether and where to grow the crop. Factors such as temperature, soil type and topography, moisture and altitude all impact on the successfulness of maize growth in GB.

Temperature

Maize drilling usually takes place in the second half of April and first half of May being chiefly governed by soil temperature. Maize Seeds germinate at 8-10⁰C and so drilling should take place once minimum soil temperature reaches a consistent 8⁰C over a period of 7 consecutive days (Draper,2013). It is important to check soil temperatures at drilling depth (between 5-7cm) daily to ascertain the trend of soil temperatures – if the soil temperature is 8 degrees but falling then drilling should be delayed as the seed will not germinate. In cold, wet soil conditions it is susceptible to seed rot from fungi and soil borne disease regardless of seed treatment (Renfro and Ullstrup,1976, van Veen *et al.*,1997, Chiarini *et al.*,1998, Draper,2012).

Over a complete growing season a maize crop needs a set amount of solar energy in order to develop from germination through to harvest (Phipps *et al.*,1974). Ontario Heat Units (OHUs) are the most common unit of measurement for establishing the amount of solar energy any site receives. OHU's for a site are calculated by using the maximum daily air temperature above 10⁰C and the minimum daily air temperature below 5⁰C, between May 1st to October 31st in the following formula (AFBI,2013):

$$\text{Daily Ontario Heat Units} = (Y_{\text{max}} + Y_{\text{min}}) \div 2$$

where:

$$Y_{\text{max}} = (3.33 \times (T_{\text{max}} - 10)) - (0.084 \times (T_{\text{max}} - 10.0)^2)$$

where T_{max} is daily maximum air temperature

and

$$Y_{\text{min}} = (1.8 \times (T_{\text{min}} - 4.4))$$

where T_{min} is daily minimum temperature

Any negative values for T or Y max or min are entered as 0.

OHU requirements for successful forage maize growth have been estimated to be about 2,300 units (Phipps and Wilkinson,1985, Morgan,2013). North of this line it has been found that OHU had a negative effect on dry matter (DM) of harvested maize forage however, Potts *et al.* (1979) observed that it is possible to grow maize successfully on sites where 2,300 was recorded.

Recent developments in plant breeding have reduced OHU requirement for earlier maturing maize varieties (Farrell and Gilliland,2011, Gilliland and Meehan,2011) which means that significantly larger areas of the UK are suitable for maize production compared with the 1970's and 1980's. It seems that the long term trend of OHUs in the UK has remained relatively consistent with the figures seen in 1985, however there is significant variation from year to year which suggests that consistent maize growing may be difficult in more marginal areas (AFBI,2012). Data generated in Northern Ireland (Figure 1), where maize growing is marginal, shows how much variation there can be in OHUs year on year. As the trend for temperature rise in the UK looks unlikely to change and varieties continue to be bred for earlier maturity it is likely that maize growing in the UK will remain viable and become more consistent on favourable sites and increasingly viable in marginal areas. Marginal areas with a low winter rainfall will be first choice for testing maize in new areas to increase the chances of a successful late harvest.

Harvest year	OHU 1 May - 31 Oct	Trial sites
1997	2368	Dromore
1998	2250	Dromore and Comber
1999	2407	Dromore and Comber
2000	2256	Dromore and Comber
2001	2393	Gransha
2002	2100	Gransha
2003	2338	Gransha & Comber
2004	2385	Gransha & Comber
2005	2303	Gransha & Comber
2006	2632	Gransha & Comber
2007	2375	Gransha & Comber
2008	2289	Gransha & Comber
2009	2409	Gransha & Comber
2010	2497	Gransha & Comber
2011	2140	Gransha & Comber
2012	2111	Gransha & Comber
16yr Mean	2328	Average of 1997-2012

Figure 1. OHU on sites in Northern Ireland <http://www.afbini.gov.uk/reclists-foragemaize-growing>

Soil type and topography

Maize is able to be grown on a wide variety of soil types. Soil type will influence drilling dates and the ability to harvest a crop successfully to a greater extent than combinable arable crops. As a spring sown crop requiring temperatures of at least 8°C for germination it is important to note that dark soils and soils with light textures warm up much more quickly than heavier and wetter soils (Phipps and Wilkinson,1985). Maize will grow successfully on soils with a pH in the range of 6 to 8 (Bunting,1978).

Furthermore soil type has a significant effect on moisture content and subsequent plant development. Light soils tend to retain less moisture than heavy soils which may be problematic during drought conditions. Heavier soils are more prone to water logging which can delay planting and make late autumn harvesting more difficult(Draper,2005). Soil type has a marked effect on microbial content established within the rhizosphere due to differences in soil texture, pH and drainage which in turn impacts on the nutrient availability

to plant roots (Groffman *et al.*, 1996). Nitrogen fixing microbe populations such as *A. brasilense* are positively correlated with soils containing Na, Mg, Ca, higher proportions of silt and a more neutral pH, whilst are negatively correlated to sand content, N, C and P (Latour *et al.*, 1996, Chiarini *et al.*, 1998). Better quality soil will positively affect maize crop performance due to better nutrient availability to roots from microorganisms in the soil.

Fields with a south facing aspect will warm up much quicker in the spring than north facing fields and as such it will be possible to drill earlier in these locations. If north facing slopes don't warm up to the required temperature by mid-May then they are not suitable for growing maize as the harvest of the maize would be delayed too late into autumn and early winter (Phipps and Wilkinson, 1985).

Moisture

Maize seeds and seedlings require moisture to enable germination and ongoing development. Maize should be drilled to the soil moisture if rapid germination is to follow (Draper 2003). The level of soil moisture is usually identified by eye following the digging of a test hole (Morgan, 2013). The US Department of Agriculture produces an excellent guide to assessing moisture by soil type with pictures and is readily available from

<http://www.oneplan.org/Water/soilmoist.pdf> or

http://www.nrcs.usda.gov/wps/portal/nrcs/detail/mt/newsroom/?cid=nrcs144p2_056492.

Other techniques involving oven drying and tensiometers are available and will give accurate readings but are deemed too complex, time consuming and expensive to make them popular (Morgan, 2013). Typical drilling depth for maize seed is from 4-8cm, depending on soil type (deeper on light soils), maize will not germinate in dry soil so ensuring good seed to soil contact with enough moisture is essential (Morgan, 2013). Maize drilled at a deeper depth will take longer to germinate and establish, due to the lower soil temperatures than shallower drilled crops, however seeds should not be sown too shallow or they will be vulnerable to predation from birds which can lead to significant losses (Morgan, 2013). Cultivation can have a significant impact on soil moisture and this is discussed in chapter 3.

Altitude

As altitude increases air pressure decreases and consequently temperature drops. This long established scientific theory is known as the lapse rate and the temperature drop is roughly 0.65°C per 100m gain in height dependent on time of day and humidity. Altitude linked cooling can be problematic when waiting for soil temperatures to reach 8°C in order to begin drilling, the higher the altitude the slower the soil will be to warm up, consequently drilling will

be delayed and the growing season shortened. This cooling effect linked to increasing altitude limits, in most circumstances, maize growing to fields below 305 m (1000 feet). When sowing maize at or around this upper margin, site selection is particularly important with sheltered free draining soils providing the best opportunity for successful crop harvest with little or no soil related problems. It is likely that due to on-going climatic change the altitude at which maize can be grown will be higher than it is currently.

Conclusions

Site selection is one of the most important considerations in growing a maize crop due to the marginal nature of the UK growing conditions. There can be very large differences from year to year in OHUs received by any one site, and such variation needs to be considered to minimise the risk of crop failure in years where OHUs are low. Lower altitude, sheltered and south facing fields are the prime locations in order to maximise growing potential. Marginal areas within the UK can still grow excellent maize crops most years and sound agronomical choices can improve the chances of success – selecting earlier maturing varieties with lower OHU requirements will lead to a faster growing crop which can be harvested earlier in the year to avoid potential pitfalls associated with later harvests. Furthermore technologies such as growing maize under plastic (chapter 4) can have a very dramatic effect in warming up soils and speeding up germination and establishment of the crop and is used extensively in Ireland, however it is expensive and this must be taken into consideration.

Chapter 2 – Selecting Seed Varieties

There are over 150 maize varieties available in the UK that have been tested via the NIAB/TAG National and Descriptive list trials and are freely available from http://www.niab.com/pages/id/332/Forage_Maize_Descriptive_List. Unlike Recommended Lists, used for other cultivars which incorporate an element of variety selection, all maize varieties tested are catalogued in a descriptive list. Participating breeders and merchants pay for their varieties to be trialled and ‘described’. Quality, maturity, and agronomic performance of each variety are set out in one of two lists. Varieties on the first choice list have no significant quality, yield or agronomic issues whilst varieties on the second choice list are deficient in at least one of these aspects. The majority of UK maize varieties are selected from the first choice list. Due to the nature of the list it is difficult to give solid recommendations; the earlier maturing varieties will be most attractive to UK growers and crucial to those farming in marginal maize growing areas (Morgan,2013).

Maize suffers from few diseases and so until very recently no disease data was collected during the national and descriptive list trials programme. Maize Eyespot (*Kabatiella zeae*) has in the last five years become a significant disease of maize and as a consequence varietal differences are now being recorded by NIAB. While varietal susceptibility to Eyespot has been identified, insufficient data is as yet available to make recommendations.

Conclusion

Whilst there is information available to producers on available varieties and their potential suitability to certain locations, this data could be improved markedly. It would be valuable to growers to have more information on earliness of varieties and the number of Ontario Heat Units on the sites where these trials have taken place. This way varieties could be more easily tailored to the specific growing conditions on individual farms.

Chapter 3 - Seedbed Preparation and Sowing

Introduction

There are several key factors pertaining to seedbed establishment (Demmel,2012):

- Yield potential and expectation
- Soil type + risk of erosion
- Climate; risk of drought/water logging, rainfall/soil warming
- Rotation; previous cropping/crop residues
- Acreage and labour capacity
- Mechanisation
- Slurry/farm yard manure applications/starter fertilisers and their placement

Maize can be grown on a variety of soil types however the principles for seedbed preparation are the same. A firm, fine seedbed with a deep, aerated root bed are desirable (Bunting,1978, Phipps and Wilkinson,1985, Draper,2013) however the methods of achieving this have changed since maize's introduction in the UK due to improvements in machinery and a better understanding of the crops requirements. Maize is particularly sensitive to soil compaction and so elimination of this is the key to a productive crop. This is due to the deep rooted nature of the crop – previous research in California found rooting to the depth of 2.5m in dry conditions with no irrigation (Stewart *et al.*,1975). In the majority of cases a rooting depth of between 1.0 to 1.7m can be expected (Doorenbos and Pruitt,1977) and in UK trials it has been shown that roots will reach at least 1.0m provided there is no physical barrier (Carr and Hough,1978) so it is important to cultivate as deep as possible when necessary. Correct tillage to eliminate natural and induced compaction will improve rooting depth and

formation leading to better water and nutrient uptake and spurring plant growth and yield (Unger and Kaspar,1994). Previous research showed a yield loss of 26.8% in year one and 14.5% in year two of maize plots which weren't sub-soiled compared to those which were – sub-soiling can reduce compaction and improve yields (Abu-Hamdeh,2003).

Traditionally in the UK, the method for establishing a suitable seedbed was to plough early and leave the field fallow over winter for a weathering effect where large clods are broken down to improve soil structure. Sub-soiling may be carried out if there is a known risk from compaction, this is best done in dry conditions late in the autumn/early winter to maximise shattering of the soil (Limagrain,2010). Subsequently, this would be cultivated in spring and drilled – farm yard manure or slurry may be applied over the course of the winter depending on availability (Pain,1978, Phipps and Wilkinson,1985, Draper,2012). Recent trials in Europe and the UK have found that ploughing still results in the best root formation and yield results (Carpentier *et al.*,2012, Draper,2012, Mikkelsen,2012, Oost and Depoorter,2012). However, as fuel prices have increased the profit per hectare from yield through ploughing gets smaller so some have looked at alternative, reduced cultivations to cut costs – furthermore there are positive effects relating to the environment to be gained from reduced tillage such as reduced fuel usage (Draper,2010). Furthermore reduced tillage tends to leave more crop residue on the surface which can reduce soil erosion and improve water retention in soil (Linn and Doran,1984, Klein,2012). Finally overwinter crop residues provide a beneficial food source to bird species through months where other food sources are less abundant (Moorcroft *et al.*,2002, RSPB,2014).

No and reduced tillage

Direct drilling of seed into the residues of previous crops is the cheapest way of establishing a maize crop. It is also beneficial for reducing loss of moisture and soil (Azooz and Arshad,1995, Trojan and Linden,1998). Conventional tillage alters pore size and their distribution within soil (Hermawan and Cameron,1993, Azooz and Arshad,1995) and the increased aeration tends to increase high-metabolic bacteria in the soil but reduces fungal growth (Pankhurst *et al.*,2002

). A significant increase in microbial biomass from fungi has been found in reduced tillage and no tillage systems(Beare *et al.*,1997, Frey *et al.*,1999) due to the increased residues in the top layer of soil (Spedding *et al.*,2004). However, despite these improvements it has been shown that reduced yields are to be expected from reducing tillage, and no tillage, for maize growing due to poorer soil structure inhibiting root growth and movement of water and

nutrients. In the UK reduced tillage is likely to be of interest in soils of high sand content and low rainfall where moisture and soil conservation is an issue. Well-structured, deep loam soils may also benefit from reduced tillage, provided that there is little or no compaction present. On heavier clay soils in areas of high rainfall such as found in south west England ploughing is likely to remain the first choice establishment method as soil water logging can be a problem and therefore the better drainage provided by deep cultivations will be more appropriate. Furthermore there is a proven positive temperature effect of ploughed soils when compared with no tillage systems that leave a residue. Crop residues insulate the soil and it has been shown that this slows drying of soil in the spring and thus also slows the rise of soil temperature (Kaspar *et al.*,1990, Fortin,1993) – tilled ground has the opposite effect whereby disturbance of soil air pockets increased drying of the soil and sped up spring warming (Jordan and Leake,2004, Licht and Al-Kaisi,2005). As many parts of the UK already have to use early varieties in order to make the most of the marginal maize growing climate it seems unlikely that reduced tillage will be an option for most maize growers.

The Maize Growers Association in the UK has carried out some trials where reduced cultivations used between 35-45l/Ha of diesel compared with the control of flat lift, plough, power harrow and drill which used almost 55l/Ha (Draper,2010, Draper,2012) but the trials have been very limited in scale and limited to only one trial site in Cheshire, further research in this area is definitely warranted to determine how big a contribution reduced tillage could make to UK maize growing. Soil type and topography will have a big impact on fuel consumption on different farms; hill farms with heavy soils will likely use more fuel per hectare than a flatter farm with lighter soils. However if fuel prices continue to rise, as seems likely, reducing tillage will become a more attractive proposition to cut costs unless a sufficient increase in milk, beef or grain maize prices occurs. The speed at which the economics are effecting the research can be seen in a 2007 study where red diesel price at 36p/l is used to conclude that the profit from plough systems is higher than non-inversion tillage (Bailey,2007, Morris *et al.*,2010) but in 2012 the fuel price used in a study was 70p/l leading to totally different conclusions on the viability of non-inversion tillage (Draper,2012). More research needs to be undertaken to assess the future value of non-inversion tillage in relation to increasing fuel prices.

Strip tillage

Strip tillage is a form of reduced cultivation where only part of the land is inverted, leaving non-inverted strips in between. Rows of crops are then established in the inverted soil with the in between strips remaining with residue cover. In this system the growing crop benefits

from the improved structure and soil warming of the inverted strips whilst the inter row parts with crop residue retain moisture and reduce soil erosion (Licht and Al-Kaisi,2005).

Penetration resistance of soil under strip tillage to maize roots has been shown to be lower than no tillage systems allowing for better maize crop establishment (Unger and Jones,1998) but is higher than that seen where fields have been ploughed (Erbach *et al.*,1992).

Strip tillage is popular in the USA for maize growers and is starting to see uptake in France and Germany (Demmel,2012) but UK research into strip tillage for maize is very limited. Row width will be determined by the machinery available but traditionally would be 75cm apart (Williams,2011)

Weed and Disease Problems

One of the biggest doubts surrounding non-inversion tillage is that it confers none of the benefits of ploughing with regards weed and disease control.

Although little research has been published in the UK on non-inversion tillage systems in maize crops, research on wheat has shown that non-inversion tillage shifts the pattern of weed species seen in a field from broad leaved weeds to grass species (Froud-Williams *et al.*,1984, Morris *et al.*,2010). Some grass species, such as black-grass (*Alopecurus myosuroides*), are becoming more resistant to herbicides which means a more difficult and costly procedure to remove them (Holt *et al.*,1993, Cummins *et al.*,1999, Moss and Clarke,2008) – potentially reducing the profitability of non-inversion tillage. Further UK research on the timing of cultivations under this system and their subsequent effect on weed populations is needed.

Disease control can be a large problem with maize grown continuously and if this is to be done then non-inversion tillage is not an option. Stalk rot caused by *Fusarium* spp. is a major soil borne disease of maize but can also effect other cereal crops(Cook,1978) so rotation where wheat follows maize and vice versa should be avoided. *Fusarium* is also a cause of mycotoxins which can be dangerous to animal health. Maize Eyespot (*Kabatiella zeae*) a fungal disease transmitted from plant to plant by spores associated with crop trash being blown around on the wind, presents another big challenge to UK maize crops, particularly those in the wetter cooler west of the country. In general non-inversion tillage should be used on fields where there is no known weed or disease problem. If continuous maize is unavoidable on a site then deep ploughing to bury trash and break disease cycles is the best course of action. Weeds and diseases will be discussed more thoroughly in later chapters.

Maize under plastic

It is possible to grow maize under degradable starch plastic which is laid down at drilling. The plastic warms up the soil below it and in so doing allows farmers to drill earlier and have earlier crop establishment and harvest date with better yield and DM accumulation (Messer, 1978, MGA, 2011). Previous research has shown that the use of mulch plastic increases soil temperature and speeds up emergence of the crop by as much as 10 days when compared with no plastic mulch (Easson and Fearnough, 2003) and reduce time to silking by up to 19 days compared with no plastic (Farrell and Gilliland, 2011). Due to the effect plastic has on raising soil temperature it is possible to establish a maize crop earlier in the year and the OHU requirement to reach silking can be reduced by 15% (Easson and Fearnough, 1999). Plastic mulch can increase whole plant dry matter by 4% at harvest compared to a crop grown without plastic which also leads to an increase in starch content of the crop (Easson and Fearnough, 1999, Easson and Fearnough, 2003). Total DM yield increased by 2.7t DM/ha (Easson and Fearnough, 1999), 2.4t DM/ha (Easson and Fearnough, 2003), 2-3.5t DM/ha (Keane *et al.*, 2003) 3.9t DM/ha (Farrell and Gilliland, 2011) when plastic was used. Sheet type plastic mulch produced the best results for earlier drilled crops where plant damage sustained when breaking through the plastic was offset by the significant gains in soil and air temperature when compared with punch type plastic (Easson and Fearnough, 2003). Punched plastic (where holes in the plastic are made above seeds) had favourable results for later drilled maize crops where the earlier exposure to ambient air temperatures caused by the punched holes was not a big disadvantage (Easson and Fearnough, 2003). The addition of plastic film requires specialised machinery and adaptation of the system to work in widths suitable for this machinery, the additional cost of growing maize under plastic has been estimated at anywhere between £100/acre and £200/acre although it is difficult to get a definitive value as the contractors and farms using this system are very much in the minority. Further research into the extra cost of maize under plastic to create a cost-benefit analysis based on sound data would be very useful to the UK industry. On the whole maize under plastic is seen as most useful for farms in marginal areas such as Northern Ireland, Scotland and northern parts of England where drilling dates will be later due to soils warming slowly in the spring, in these areas plastic mulch can help farms to grow maize more consistently year on year despite fluctuating conditions and OHU levels.

Conclusion

It can be seen that maize growers in the UK have developed a reliable method for growing the crop successfully in a marginal climate. The key factor influencing a successful establishment is to drill at the depth moisture when the soil has reached a consistent temperature of 8°C (as discussed in chapter 1). Ploughing has been shown in several studies to result in the highest yields but there are certain situations and site conditions where alternative cultivations may be desirable to reduce compaction, soil and water loss. Maize has traditionally been grown in rows however improvements in harvesting machinery has allowed use of cereal drills with a seed rate of between 47,000 to 50,000 seeds per acre (\approx 116,000 to 124,000 seed per hectare) being recommended by the MGA for maximising dry matter yield when drilled between 4-8cm in depth (Morgan,2013). Seed treatments are considered effective for improving germination and survivability of maize plants by providing protection from some soil pests and diseases as well as making seed less palatable to birds (Morgan,2013), however there is a risk of products being banned in the future, as was the case with Poncho in 2013, due to environmental impact (MGA,2013). Further UK research would be beneficial to further establish benefits of reduced and no tillage. Research into weed and disease problems associated with establishment technique are very limited for maize, with the best indications coming from wheat research. More UK research for this would be desirable to increase understanding and improve advice for producers considering using reduced tillage. Finally maize being grown under plastic has been proven a valuable technique in marginal areas – however as our climate warms and maize varieties become earlier, the necessity for it should reduce and producers may be keen to eliminate this cost from production whilst others will seek to utilise it in areas where maize has never been previously grown.

Chapter 4 – Nutrient requirements and fertilisers

Introduction

As with all farmed crops steps can be taken to ensure that a maize crop reaches its potential yield and quality beyond that which the soil would provide on its own. Soils are often very high in most nutrients however they are often unavailable to plants as they are stored in complex compounds that cannot be used by vegetation (Pain,1978). As for most crops, the major nutrients required by maize to maximise crop growth and yield are nitrogen (N), phosphorous (P) and potassium (K).

Nitrogen

Most N in soils is in the organic form and is made available to plants through mineralisation processes but not in the quantities necessary to maximise maize growth. In temperate regions it is estimated that 1-2% of total soil N may be released in a growing season and in fertile soils this may be equivalent to 80-100kg/ha (Pain,1978). Most of this is available as highly water soluble nitrates because ammonium in well aerated soil, such as that required for growing maize, is quickly nitrified by bacteria. In poor structured and waterlogged soils nitrates will be denitrified under anaerobic conditions by heterotrophic bacteria into nitrous oxide (gas) which escapes the soil and is a major contributor to global warming. Nitrogen availability is greatly influenced by soil type and previous cropping regime and so generalised recommendations for N applications are difficult but 100kgN/ha is often stated a reasonable starting point for most producers (Morgan,2013). The DEFRA RB209 fertiliser manual

(https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69469/rb209-fertiliser-manual-110412.pdf) assists farmers in tailoring N applications to the requirements for each field. The MGA offer a “Nitrogen Predictor” service where individual field history and N response trial data are used to produce an individual field recommendation.

Nitrogen deficiency in growing maize plants is characterised by slow initial growth, yellow leaves and premature senescence of leaves (Pain,1978). Deficiency may be because of insufficient available N in the soil or due to drought conditions preventing plants from taking up nutrients (Pain,1978).

Phosphorus

Phosphorus is essential for development of cell nuclei, cell division and development of meristematic tissue (sites of new growth such as stem and root tip and is therefore very important early in plant development to promote good root and plant growth (Pain,1978). As P is important in the early stages of growth, up to the 6 leaf stage (Barry and Miller,1989, Hajabbasi and Schumacher,1994), late applications of P will not reverse any negative effects already suffered. As with the other nutrients soil testing is crucial to determining how much P is needed as fertiliser but a figure of around 50-60 kg/ha of phosphate would be typical for most UK soils(Pain,1978, Phipps and Wilkinson,1985, PDA,2008). A maize crop of 40t/ha fresh weight will take around 55kg/ha P_2O_5 from the soil (PDA,2008). The DEFRA RB209 fertiliser has a section on phosphorus for forage maize which is a key resource for UK farmers. P deficiency is typified by slow development of seedlings and reddening/purpling of

older leaves (Pain,1978). P deficiency can be compounded by N deficiency, with P uptake reduced by up to 70% when N supply is inadequate(Pain,1978).

Potassium

Potassium maintains the rigidity of fibre in the plant which prevents lodging and stops leaves from sagging(Pain,1978). Photosynthesis is aided as a result of adequate K supply due to its essential role in the opening and closing of stomata dependent on time of day (which also improves water use efficiency) as well as the effect it has on increasing leaf size compared with K deficient crops (Pallaghy,1971, Pain,1978). Due to its benefit in terms of preventing lodging and maintenance of healthy leaves yield increases have been observed when maize is treated with K fertiliser (Pain,1978).

As with the other major nutrients, soil supply should be calculated through lab analysis in order to accurately predict the amount of K fertiliser needed on the field. A 30t/ha crop of maize removes 130kg/ha K_2O and a 50t/ha crop removes up to 220kg/ha K_2O which must be returned to the soil through fertilisers; FYMs are high in K so are often the best way of putting K back into the soil (Pain,1978).

K deficiency in young plants is typified by slow development and light green leaves with yellow streaks. Older plants have brown leaf tips and are more susceptible to stalk rot and lodging, despite having stunted growth and cobs may not fill well (Pain,1978).

Starter fertiliser

Starter fertiliser is placed to the side of and/or underneath rows where the maize seed is drilled in order to provide a localised source of nutrients for the growing seedling. This practice has shown to improve establishment of maize seedlings when N and P fertilisers are used as a starter in conjunction (Pain,1978, Randall and Hoeft,1988, Schroder *et al.*,1997, PDA,2008) and may also see a response in starch yield (Draper and Baker, 2002). This type of application is only effective in soils with a low P index and is not usually necessary if manure has been applied in the spring (PDA,2008). The DEFRA RB209 fertiliser manual recommends all P and 10-15kg/ha of the N requirement is placed just below the depth that the seed is drilled at with the remainder of the N being top-dressed once the crop has emerged.

Organic Manures

Maize is a good crop onto which to apply organic manures (primarily farm yard manure (FYM) or slurry) in spring when it is not possible to spread elsewhere on the farm. Maize P

and K nutrient requirements tend to match the profile provided by farm produced organic manures; in many cases only additional inorganic N will be required on top of manures. Over spreading of manures, on what are sometimes called “sacrifice areas”, has become a genuine environmental concern as discussed further in chapter 10. Manures should be analysed where possible to ascertain their nutritive value and their application limited so as not to exceed crop requirements or regulatory limits (the 250kg N/ha NVZ and Code of Good Agricultural Practice limit). Many organisations provide estimates/averages of the nutrient content of different manures in case a representative sample cannot be analysed – DEFRA’s Fertiliser Manual is the base publication used by specialists in the field. The Fertiliser Manual has been computerised and made available via various commercial software packages and the PLANET programme. The organic manures element of the fertiliser manual is available via a very simple ADAS produced computer programme called MANNER. An example of typical nutrient content of common manures from the PDA is included below.

Available nutrients for the next crop following spring application

	kg per tonne or per cubic metre		
	N	P ₂ O ₅	K ₂ O
Cattle FYM	1.2	2.1	7.2
Broiler litter	9	15	16
Cow slurry	1.0	0.6	3.2
Pig slurry	2.0	1.0	2.3

Manure applied before February may only have half the available nitrogen of a spring application.

Figure 2 PDA guide to FYMs <http://www.pda.org.uk/leaflets/pdf/PDA-lf17.pdf>

Conclusion

Ensuring that maize receives sufficient nutrients is vital in order to maximise profitability. A nutrient deficit will reduce yield and potentially quality of the crop whereas a surplus will be wasted money on expensive fertilizer as well as be potentially harmful to the environment due to nutrient leaching into water courses. There is much research into the correct use of inorganic fertilizers in the UK and most farmers and contractors are able to access excellent information on this subject. There is less certainty when organic manures are being used and further steps should be taken to help farmers understand the nutrient content of organic manures and of the potential harm of over application. This is discussed further in chapter 9.

Chapter 5- Crop Maintenance

Introduction

Maize continues to be seen as relatively healthy compared to mainstream UK agricultural crops. Initially, maize had relatively few significant pests and diseases primarily because there was no existing reservoir for maize pathogens and pests and the climate was too cold for their development (Cook,1978). Over time European pathogens have adapted to UK conditions and there have been new threats to the maize crop. The transmission of disease has been aided by a large increase in the area of maize planted. The steps taken by producers to counter these problems are essential to profitable production.

Maize eyespot

Maize eyespot (*Kabatiella zeae*) is a fungal disease that can cause yield losses between 25-80% depending on the severity of infection (Draper,2009, Trenary,2012). It usually occurs in cold wet conditions when temperatures are around 10-12°C, eyespot is generally controlled when temperatures exceed 28°C (Draper,2009).



Figure 3 – increasing levels of eyespot infection on maize leaves from:

<http://www.fwi.co.uk/articles/10/08/2012/134433/increasing-maize-eyespot-reported-across-the-country.htm>

Control of eyespot can be achieved with appropriate fungicide treatments but prevention is the best way to stop it becoming a problem (Draper,2009). Removal or incorporation of crop residue and selection of varieties appropriate for wetter and colder climates should reduce the risk of the disease in following maize crops (Pain,1978, Draper,2009).

Fusarium

The most common fungi found on maize seed are *Fusarium* species which cause root, stalk and ear rots in maize plants that can reduce yields by 10-30% (Cook,1978, Logrieco *et al.*,2002). Additionally there are some strains that produce mycotoxins which are toxic to livestock and humans and over 25% of maize is likely to be infected to some degree (Logrieco *et al.*,2002). The key mycotoxins produced by *Fusarium* in the UK are trichothecenes, zearalenone and fumonisin and these are from a wide variety of species of which the key ones are *F. culmorum*, *F. graminearum* and *F. Avenaceum* (Cook,1978, Logrieco *et al.*,2002). More information on the dangers of mycotoxins is available to growers from the UK government (FSA,2007). The challenge with *Fusarium* is that it also attacks other cereals and that repeated maize growing on a site can build up dangerously high levels of *Fusarium* in the soil which can affect following crops – therefore wheat immediately before (as a source of *Fusarium*) or after a maize crop should be avoided (Cook,1978). Removal or deep burying of crop residues is vital to preventing a build up of *Fusarium* in the top soil which may infect future crops in the rotation.

Common Smut (*Ustilago maydis*)

Common smut is a fungal disease where large galls form on the plant with an earlier immature white stage which develop to a black stage (Cook,1978, McMeekin,1999). In Mexico the white stage is considered a delicacy whilst the black stage is not usually eaten (McMeekin,1999), this market is not exploited in the UK. A severe smut infection can reduce DM yield by a small amount (Pataky and Snetselaar,2006), for example 2% in a crop (Cook,1978) but is not the most widespread disease and its economic impact to farms is usually quite small. Studies have found that the ingestion of maize silage infected with smut by cattle had no detrimental health effects (Christensen,1963, Cook,1978, Cole *et al.*,2001). Control of smut is best carried out through deep burying of infected residues, crop rotation to reduce soil contamination, and using seed treatment; however the best control is through selecting resistant varieties (Pataky and Snetselaar,2006).

European Corn Borer (*Ostrinia nubilalis*)

Corn borer is a major pest of maize worldwide and is transmitted via a highly adaptable species of moth which lays its eggs on maize leaves in June. Eggs hatch into larvae 10 days later and eat leaves and bore holes into the stalk where they either travel up to cob or down to the stalk base where tissues are softest. Frost resistant larvae then overwinter in crop residue/stubble and hatch out in late May as moths and the cycle is repeated (Cook,1978, MGA,2010). Damage to the crop is either through cob damage and subsequent infection by

other pathogens such as *Fusarium* or from stem damage that causes the crop to lodge (MGA, 2010). Insecticide can be used to control the larvae, but only becomes economic in severe cases with more than 1 larvae per plant (Leclant, 1976). Good rotation and cultivations, reduced harvesting height, and deep burying of residues will cause significant disruption to overwintering larvae by removing much of the matter in which they will reside (MGA, 2010). Seed treatment will also provide some resistance (MGA, 2010).

Frit Fly (*Oscinella frit*)

Frit fly is the most important pest of maize economically, capable of causing significant plant death. The fly has 3 or 4 generations in a year, the first of these generations hatches in late April/early May having overwintered on grass and cereal shoots and is the generation that mainly affects maize (Cook, 1978, Gratwick, 1992). Frit fly maggots hatch and burrow into the young plants and either travel up or down the plant. If they travel down they may damage the apical meristem and can completely kill the plant or cause tillering, travelling upwards causes less severe damage to leaves (Cook, 1978, Gratwick, 1992). When the plant tillers they may in turn be attacked by maggots and the plant height and yield will be reduced, cobs will form lower down the plant, be smaller and unprotected (Cook, 1978, Gratwick, 1992). Control of frit fly can be achieved with insecticide seed treatments or as a contact spray as soon as infection is detected, as well as good agronomic practice such as leaving ploughed land fallow longer before drilling a susceptible crop to break the lifecycle.

Other diseases and pests

There are a multitude of other diseases and pests of maize with varying degrees of prevalence in different parts of the country. There are already good publications available free for growers to refer to that give detail on the whole spectrum of pests of maize such as those produced by KWS (available from http://www.kws-uk.com/global/show_document.asp?id=aaaaaaaaaneoau&download=1) and Limagrain (available from http://www.gpfeeds.co.uk/ebooks/maize_a_growers_guide/files/forage%20maize%20technical%20guide%202011.pdf)

Conclusion

Maize in the UK has been relatively free of pests and diseases to the benefit of producers, especially when compared with other crops grown here. However as the area of maize has increased the risk of transmission has also increased. If a new pest or disease enters the country it is likely to spread more quickly and be more difficult to quarantine and eradicate.

Furthermore as our climate warms it is likely that more pests and diseases associated with mainland Europe will be capable of establishing themselves in the UK. In terms of research this means that an understanding of European pests and diseases is important so that if they become prevalent in the UK, producers will already know what to expect and how to eliminate it.

Chapter 6 – Harvesting

The timing of maize harvest is dictated by a number of factors, including drilling date and subsequent weather, but harvest date is critical to the ultimate quality of the crop. In the UK a lack of OHUs during the growing season can delay harvest into wetter Autumn weather and potentially impinge on the ability to harvest the crop and reduce its feeding value.

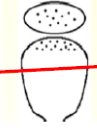











When to harvest

As discussed later in Chapter 9 the optimum dry matter (DM) of maize for feeding to dairy cattle has been determined to be around 32% - the MGA in the UK recommend trying to harvest with a whole crop DM in the range of 28-35% (Draper *et al.*, 2012) . With this in mind harvesting should aim to take place when the whole crop DM can be determined to be within a range of 28 – 35%. When this occurs will depend on when the crop was planted and the environmental conditions at planting and during growth of the crop. There are several tests that can be undertaken 'on farm' in order to estimate whole crop DM in the field:

- The so called 'thumb nail' test requires a representative sample of cob from across the field, avoiding headlands and obvious struggling patches and also any patches significantly better than the average crop. The grains at the top of the cob should be like soft cheese, the ones at the bottom should be like hard cheese and the ones in the middle should be soft enough to leave the imprint of a thumbnail on. When these middle grains can take a thumbnail imprint then the crop is ready to harvest (Advanta, 2002)
- Kernel milk line test- there has been a scientifically proven relationship between the kernel milk line and whole crop maturity (Afuakwa and Crookston, 1984, Crookston and Kurle, 1987, Ganoe and Roth, 1992, Wiersma *et al.*, 1992) which makes it a more reliable visual test than the thumb nail approach. It is also easy to undertake in the field. The MGA have produced an excellent table of what to look for under UK field conditions

which is reproduced here with their permission (MGA,2013)

MILK LINE TEST DRY MATTER GUIDE

Grain Stage	Milky	Milky doughy	Doughy milky	Doughy	Hard dough	Hard and glassy
Grain Aspect (from central crown)	All milk - no milk line	Milk line begins to show from the top	Milk line 1/4	Milk line 1/3	Milk line 1/2 and top becomes glassy and hard	Top half of grain glassy and hard, no milk stage
Husk	Green	Green	Green	Yellowing	Yellowing	Desiccated
Grain DM %	Less than 52%	Less than 52%	52	55	58	More than 58
Kernel						
Milk Line						
Whole Plant DM%	Less than 25%	25-28	28-30	30-32	32-35	More than 35

- Oven DM test, a representative sample of the maize crop (200-500g) needs to be taken from the field and cut into pieces and weighed then dried for 24 hours at 100°C (until weight loss stops) in an oven and reweighed. The relationship of fresh weight to dry weight will give the DM for the crop.
- Microwave DM also requires a representative sample cut into small pieces, weighed, and then microwaved for several minutes and then checked for the amount of weight (moisture) loss. Exact timings are difficult to recommend and will vary greatly by crop DM and microwave used, initial times may be 5-10 minutes but as the crop gets drier 30 second intervals will be appropriate – great care needs to be taken as the crop dries as it may smoulder or ignite. The aim is to do several microwave steps, reducing the length of time in the microwave, weighing each time until weight does not change for 2 consecutive measurements. This is much quicker than the oven test and can process several samples quickly from different fields whereas oven space may be limited and may not be appropriate as the silage creates a strong smell when dried. There are several websites that provide similar instructions for this process such as the one cited here from the University of Connecticut's agricultural extension service (Morgan,2013).
- It is possible to just do DM test of the cob rather than whole plant DM in the oven or microwave – grain DM of about 55% is achieved when whole crop DM is about 32% however it will be more accurate to do a whole crop DM in cases where crop growth or cob formation is stunted or in some way unusual.

It is important to note that the sample analyzed for DM content using these procedures should be as representative as possible of the whole crop, including the stalks, leaves, and ears. In this regard a food processor or other mechanical chopper may be useful.

Predicting the date of harvest from one of these tests is key to harvesting the crop at the optimal time, you could of course check DM every day, however you can also calculate your expected harvest date from the maize dry down rate. Under UK conditions, once past a whole plant DM of 20%, the crop dries at a rate of 2% week (Draper *et al.*,2012). This means, for example, that when the 20% DM stage has been reached it will take about 6 weeks for the crop to reach its optimum harvesting date. It is advisable to sample at least once a week during this period to allow time to prepare clamps and organise contractors. Poor weather can quickly take a maize crop beyond its optimum harvest point and all efforts should be made to harvest before the crop exceeds 35% DM. Furthermore the effect of early frosts or frost on late maturing varieties can dramatically alter the DM content of the crop, depending on the severity of the cold the crop experiences. Frost will dramatically increase DM due to killing of leaves but will also affect quality as it reduces sugar content in the crop and increases ADF, NDF and lignin content (St. Pierre *et al.*,1987, Advanta,2002, Kwabiah,2005), as well as potentially encouraging development of moulds and yeasts on the crop that will be ensiled and may cause problems later on when feeding (Advanta,2002). The UK advice in this case is to harvest within 7 days of a severe frost or before the third frost when they are milder (Advanta,2002, Draper *et al.*,2012). US research classifies severity of frosts based on its effect on the maize plant, leaves are the first part of the plant to suffer tissue damage due to their thinness whilst the husk, stalk and grain are thicker with more thermal protection and so tissue will not suffer damage in frost so readily (Carter and Hesterman,1990, UniversityofWisconsin,2006). Maize plants will be killed when temperatures are near to 0°C for 3-4 hours or in a few minutes when temperatures drop to -2°C, although damage can occur in temperatures just above freezing if terrain and weather create 'frost pockets' i.e. when there are clear skies, no wind and low humidity (Carter and Hesterman,1990, UniversityofWisconsin,2006).

Chop Length

The length that maize is chopped is determined by the setup of the harvester used when the maize is cut in the field. The capabilities of the machinery at harvest have changed considerably since maize growing began in the UK in the 1970s. Provided a compliant contractor is used or the machinery is owned on farm already then a chop length of anywhere between 5-35mm in length (both ends of the range being extreme) can be

achieved. Having a corn cracker fitted to the harvester will crack open the grains increasing starch digestibility in the rumen (Hale,1973, Bal *et al.*,2000, Weiss and Wyatt,2000, Johnson *et al.*,2002, Ferraretto and Shaver,2012).

Different crop chop length will impact on clamp consolidation and digestion. In terms of clamp management a shorter chopped forage is easier to consolidate in the clamp due to its increased density (Wilkinson,1978, Phipps and Wilkinson,1985, Advanta,2002). As chop length increases, consolidation becomes more difficult and so in situations where a very mature maize crop has been harvested, such as one after a severe frost or late harvesting from wet weather, a shorter chop length will improve consolidation and fermentation by excluding air more effectively. Conversely a very immature crop, below 28% DM, would benefit from a longer chop length in order to improve consolidation and fermentation in a clamp as there will be less effluent produced and thus less nutrient loss. Furthermore very immature crops that are chopped short will produce significantly more effluent than a mature crop, which will produce virtually none, leading to loss of nutrients in the feed and an environmental concern should nutrient rich effluent contaminate waterways leading to eutrophication. In situations where effluent is produced it should be collected and returned to the land diluted with water at an appropriate time (Phipps and Wilkinson,1985).

The effect of chop length on digestibility and milk yield of dairy cows has been subject to several studies with varying results. Some studies found no effect from changing chop length in relation to milk yields (Stockdale and Beavis,1994, Clark and Armentano,1999, Johnson *et al.*,2002, Fernandez *et al.*,2004) whereas other studies have reported a small increase (Schurig and Rodel,1993). There is some evidence that a shorter chop length can reduce milk fat percentage (Kononoff and Heinrichs,2003) but there are other studies that found no difference (Bhandari *et al.*,2007). Short chop length maize can result in reduced cudging (rumination), saliva production and rumen buffering which could increase the risk of subacute rumen acidosis (SARA), a condition of lowered rumen fluid pH often associated with reduced milk fat concentration and health problems (Mertens,1997, Stone,2004). Research from the US is the most reliable source of information for UK farmers and their findings for chop length will be applicable here, UK research on this subject would be beneficial to the industry. The MGA recommendation is that chop length should be linked to the circumstances on an individual farm. For high forage low concentrate rations shorter chop lengths (8-10 mm) are more appropriate. For low forage high concentrate rations maize should have a longer (15-25 mm) chop to provide structural fibre for the rumen. Other UK recommendations suggest 8-10 mm (Phipps and Wilkinson,1985).

Height of Cutting

Although there is limited research conducted on the effects of cutting height, the effect it has is widely accepted. Typically the stem nearest the ground is less digestible and wetter than the grain and cob which contain more energy and are considerably drier. As a consequence the higher the crop is cut the drier and better quality it will be. The downside is that the higher a crop is cut the lower the overall DM yield. Previous research recommended a cutting height of 15cm as it increased DM yield over a 35cm cutting height (Wilkinson, 1978). Similar studies have shown that as cutting height increased from 13 to 46 cm, DM yield reduced from 15.6 to 15 tonnes DM/ha, DM% increased from 33% to 34.7% and starch % increased from 30.9% - 32.8% (Neylon and Kung Jr, 2003). Similar trends have been seen in other studies (Lewis *et al.*, 2004, Kung Jr *et al.*, 2008). The decision on cutting height may vary each year depending on quality and quantity of forage stocks. Newer varieties are thought to have more feed value at the base of the stem than those popular in the past so a lower height could be used if forage stocks are tight. Evidence to support this argument is anecdotal at present and worthy of further research (Draper *et al.*, 2012).

Conclusion

Harvesting of maize comes down to two key areas, timing and then the mechanical process by which it is harvested. There are several established methods for determining when a maize crop is ready to be harvested and most producers in the UK are already aware of these. Fortunately maize has a very consistent maturing rate evidenced by a steady weekly drop of dry matter which allows producers time to plan for harvest date. There is also an abundance of research which points to the optimum DM at harvest being 32-34% as long as this is achieved before a serious frost kill.

Cutting height and chop length of maize at harvest is an area that has seen previous research, with an interest from manufacturers of harvesting equipment. Cutting height is well understood as the wetter, more lignified part of the stem near the bottom reduces quality of the silage if cut at a low height however it does increase overall DM yield. Chop length should be tailored to each farm's own needs, depending on how they feed maize. A longer chop length will provide more structural fibre whereas a short chop length will increase digestibility. Most of this research is from the US and should be relevant for UK farmers however more UK research is desirable.

Chapter 7 – Ensiling

Introduction

When maize is ensiled it is deprived of oxygen and moisture beyond that which is stored with it when sealed. These anaerobic conditions allow bacteria to convert sugars in the plant into acids, mainly lactic acid and acetic acid. This causes the acid concentration to rise which stops other bacterial activity, thus preserving the maize silage for an indefinite period of time until such a time that the clamp is opened and oxygen re-enters the clamp. When oxygen and moisture are let back in the acids are broken down and/or leached out as effluent and the aerobic conditions and rising pH will allow spoilage of the preserved feed by other bacteria unless it is used swiftly (Messer,1978, Wilkinson,1978, Phipps and Wilkinson,1985).

The process of storing maize in clamps, silos, and bunkers is well understood and numerous guides are available (Messer,1978, Advanta,2002). The key points for ensiling are to ensure that the maize is being stored at a high enough density to reduce the amount of oxygen in the clamp. This is usually achieved through rolling with a tractor as each load of maize is unloaded and insufficient rolling will lead to poor consolidation and fermentation of the silage and thus reduce quality of the feed. An airtight seal over the silage is absolutely essential and is traditionally achieved with a plastic sheet that is weighed down. If used tyres are to be used as weight on plastic then they should be checked for wires as these can pierce the sheet and allow oxygen into the clamp – wires can also be a serious danger should they contaminate the feed and can lead to ‘hardware disease’ and animal death. An alternative is to use gravel filled nylon bags as sheeting weights.

When feeding maize from the clamp good face management is essential to reduce losses of DM and nutritive value. A sheer grab or block cutter should be used to keep a straight silage face; the blade should be kept sharp in order to create a clean, flat face that minimises exposed surface area to the air. The silage sheet should only be rolled back far enough to remove the next row of silage. The whole of the face should be used in turn so that no one area is left exposed for longer than the others. If the clamp is not going to be used quickly then it ought to be recovered in order to minimize contact with air.

Pest control in clamps can be important depending on the prevalence of certain wildlife in the area of the farm. Starlings, pigeons and crows can be a problem in great numbers as they can eat a large amount of the grain in uncovered silage, reducing nutritional value, and also can peck holes in silage sheets. Furthermore, bird faeces in the feed can transmit diseases, notably salmonella, but also avian TB which can cause false reactors for cows

undergoing bovine TB tests. Efforts to keep birds away from feeding areas usually involves bird scarers or shooting although netting may be possible in certain circumstances to keep birds out.

Rock salt can be applied to the surface layer of the clamp and shoulders to reduce spoilage in these areas by preventing colonisation of organisms. Applications rates should be 3 kg/m² on the top and 6 kg/m² on the shoulders (Savery,2010, MGA,2011). Many maize growers use a “cling film” type sheet known as an oxygen barrier underneath the traditional plastic. The plastic used in these sheets are less permeable to oxygen and there is evidence that this can reduce spoilage and make the clamp more stable (Borreani *et al.*,2007, Borreani and Tabacco,2008, Heron,2009).

Additives

Additives to maize silage have been extensively researched, firstly to speed up fermentation of the silage by providing an extra source of lactic acid producing bacteria to the clamp (Muck,2004) and secondly to improve aerobic stability of fermented forage when exposed to air at the silage face, in order to prevent nutritive losses caused by heating up and aerobic degradation of the feed (Wilkinson,1978, Pedroso *et al.*,2010). Much progress has been achieved with the first of these goals but at the expense of the second, in over 30% of cases the inoculants used to aid fermentation have decreased aerobic stability of the clamp (Rust *et al.*,1989, Muck,2004). Some studies have found no appreciable gain in rate of fermentation of maize (Meeske and Basson,1998) nor any effect on aerobic stability(Meeske and Basson,1998, Arriola *et al.*,2011, Queiroz *et al.*,2012). Some studies found bacterial inoculants reduced aerobic stability (Rust *et al.*,1989) and that some improved stability (Huisden *et al.*,2009, Mari *et al.*,2009). There is clearly a lot of conflicting evidence relating to inoculants for silage and the choice rests with the farmer if they feel there is a need. There appears to be some evidence that modern ‘dual-purpose’ inoculants can reduce quantity of feed spoilage from clamps but further research is needed (Queiroz *et al.*,2012).

Conclusion

In conclusion the techniques for ensiling forages remains similar to those used before but is being improved by advances in technology, both in biological and chemical manipulation of the feed stuff itself and through engineering providing superior plastic sheets and new ways to weigh them down that ease management and promote best practice. There are many claims made about these new products and continuing research will be important to

determine whether any benefits can be derived for the cost of implementation. However it is generally accepted in the industry that they achieve their stated aims (Morgan,2013).

Chapter 8 – Feeding

The benefits of maize silage feeding in dairy diets compared to grass are now well known in the industry. Increased feed intake and milk yield (Phipps,1978, Phipps and Wilkinson,1985, Phipps *et al.*,1992, Phipps *et al.*,1995, O'Mara *et al.*,1998, Phipps *et al.*,2000) have been the driving factors behind its rapid uptake by UK dairy farmers, facilitated by varieties bred to better cope with the UK climate. When feeding maize it is important to have forage that is of the correct quality and that it has been analysed so that it can be appropriately incorporated into the system. As maize silage is fairly uniform, analysis from subsamples of a clamp tend to be a more accurate indicator for the whole crop quality than those subsamples taken for a grass silage clamp.

Nutritive value of maize

Throughout the growing season the digestibility of maize remains remarkably consistent, because as the crop matures the declining quality of stem and leaves is offset by the increasing growth of the highly digestible grain in the ear (Phipps and Wilkinson,1985). Water soluble carbohydrates are stored in the leaves and stem whilst the plant is growing and are translocated to the ear to be deposited in the grain as starch (Daynard *et al.*,1969). During the translocation of carbohydrates there is also lignification taking in place in the stem and leaf leading to increased DM in the whole plant – consequently there is a relationship observed between DM and WSC that allows for a prediction to be made when to harvest for optimum nutritional qualities of the crop (Wilkinson and Osbourn,1975, Givens and Deaville,2001). However it is also proposed that DM isn't the most accurate measurement of plant maturity and that neutral detergent fibre content (NDF) may be a better indicator (Givens and Deaville,2001) however on farm the concept of DM for maize harvesting is understood, practical and reliable, especially considering the relatively small changes in digestibility that occur as the crop matures.

Maize ferments very well when clamped to form a stable, low pH feed. The maturity of the crop plays a role in the quality of the silage produced. Immature crops below 28%DM have a higher sugar content as translocation of WSC to the ear has not been given sufficient time to complete and consequently the fermentation in the clamp is more intense with the sugar being converted mainly into CO₂ and being wasted. Higher DM crops have lower sugar

contents so experience less losses in the fermentation process but still have adequate substrate (sugars and starch) to create a well preserved silage (Phipps and Wilkinson,1985).

Due to the high ME value of the grain, whole maize silage has an ME content that is typically similar to that seen in grass silage – and estimated to be on average 10.8 MJ/kg DM (Phipps and Wilkinson,1985) with a range from 10.5-12 MJ/kg DM (Advanta,2002).

Protein content of maize is low and has long been a target for breeding improvement (Gunn,1978). Crude protein (CP) of maize silage is usually within the range of 8.5-10% of DM, far lower than other forages meaning that high production animals will need additional source of protein in their diets (Gunn,1978, Phipps,1978, Phipps and Wilkinson,1985). The need to supplement maize with other feeds in order to satisfy the demands of a high production dairy cow is what has led to an increase in Partial Mixed Rations (PMRs) and Total Mixed Rations (TMRs) globally. In the US TMR systems based on maize that are nutritionally balanced using lucerne or grasses and concentrates are used in favour of traditional pasture grazing because they lead to higher yields per cow (Kolver and Muller,1998, Bargo *et al.*,2002, White *et al.*,2002). There is also evidence that grazing pastures with a maize silage-based PMR fed once per day also leads to increased milk yield compared with purely grazing but lower than a house TMR system (Bargo *et al.*,2002). UK research has also reached the same results with increasing maize inclusion also increases milk yields (Phipps,1978, Phipps and Wilkinson,1985, Browne *et al.*,1995).

Balancing diet protein supply is the most important aspect of creating a diet for a dairy cow based on maize and there are several ways of achieving this. In the UK the most common way to raise protein is to mix grass silage with maize, often using a 50:50 or 33:67 ratio (Phipps,1978). Soya meal is often used to raise CP in diets, but this is a crop that cannot be grown in the UK or Northern Europe. As a consequence the majority of the soya used in the UK is imported from the US and South America, and it is increasingly difficult to source soya meal that is not from GM varieties. To reduce the cost of importing feeds from abroad some producers use home-grown or UK sourced rapeseed or rapeseed meal as a replacement for soya or at least in a mix with soya. Studies have shown that this will usually result in a lower milk yield at the same intake (Kudrna and Marounek,2006), however the milk will be healthier for human consumption due to increasing oleic and stearic acids at the expense of saturated fatty acids (McNamee *et al.*,2002, Givens *et al.*,2003, Kudrna and Marounek,2006, Givens *et al.*,2009). One French study looking at the environmental impact of imported soya, compared with locally grown oilseed rape, found that importing soya was more

environmentally efficient (Lehuger *et al.*,2009). This was attributed to less intensive agriculture and no use of artificial fertilizers; however potential land use of soya bean production was not fully accounted for (Lehuger *et al.*,2009). The effect of increasing CP in a ration has been long understood. Trials in the UK in the 1970's found that increasing CP from 8 to 14% led to a milk yield increase of around 7 kg/cow/day (Phipps and Cramp,1976, Phipps and Cramp,1977). There has been much research done globally on this subject as increasing CP has a response in increasing milk yields, however it also leads to more N being excreted in faeces, which is both a loss in profit and also has an environmental effect to consider. One study in the US using a range of CP contents from 13.5-19.4% of DM found that milk and protein yield did not increase by feeding more than 16.5% and that the higher the CP the more that was excreted as urinary N and the lower the N efficiency of the animal (Olmos Colmenero and Broderick,2006). There have been several other lactation trials conducted with high yielding Holsteins using CP contents of between 15-17% of DM that find that increasing protein beyond these levels have no effect on milk yield (Bach *et al.*,2000, Wu and Satter,2000, Broderick,2003, Leonardi *et al.*,2003, Wattiaux and Karg,2004, Nadeau *et al.*,2007). CP is easy to alter in diets by addition of concentrates however these are often expensive and so economics will be an important consideration when formulating rations. In general, protein sources that are rumen degradable, such as rapeseed meal or urea, are fed with maize silage to provide N for microbial protein synthesis using energy derived from starch fermentation. In the UK grass is likely to be used in conjunction with maize as it is the cheapest home grown forage and can often be high in rumen degradable protein when the growing season for grass is good. Increasing concentrates in a ration depresses forage intake so a balance must be calculated between protein from concentrates (and other straights) and that from forages such as maize and grass.

Minerals and vitamins

Generally mineral content of maize silage is low, and there are numerous publications reporting the ranges of each mineral and vitamin concentrations in a typical maize crop grown in the UK – this data does not seem to have changed much as varieties have changed over the years. (Phipps,1978, Phipps and Wilkinson,1985, Advanta,2002). In a typical mixed ration mineral and vitamin supplements would be added at an appropriate level but that is dependent on what else is being fed in the ration and so it is difficult to give a generalised recommendation (Phipps,1978, Phipps and Wilkinson,1985).

Dry Matter

As discussed previously in the chapter on harvesting, research has shown that increasing crop maturity, and hence dry matter, of maize has led to improved milk yields (Huffman and Duncan, 1956, Huber *et al.*, 1965, Phipps *et al.*, 1978) although there was some debate over what the optimum DM at which to harvest was. An American study suggested that the optimum DM lay somewhere between 30 and 35% (Bal *et al.*, 1997) and a UK study concurred with these results but could not predict an optimum due to maize silages not being of the range that had been hoped for (Phipps *et al.*, 2000). The recommendation now is to harvest when maize reaches a DM of 32% (Draper *et al.*, 2012).

Conclusion

Feeding maize is probably the area that has received the most research both in the UK and abroad. Maize is a high yielding, highly digestible forage with good ME content but low protein that can be successfully grown in most of the UK. It has been repeatedly shown to increase intake and milk yield of dairy cows when included in diets at any inclusion rate. When maize is to be used as the main forage in a ration it is important to balance it with high protein feeds as maize is low in protein.

Chapter 9 – Environmental issues

Harvest damage

As previously stated the UK climate is predominantly marginal for maize growing. As a consequence maize harvest tends to take place relatively late in the autumn when the risk of soil water logging is high. The risk of fields becoming water logged before the maize harvest (typically September through to November) is especially high in the South West, Wales and Northern England (Carr and Hough, 1978). Heavy harvesting machinery used on these sites will leave behind substantial ruts in the soil and cause compaction which will need remedying through expensive cultivations; either during the winter when/if the ground is frozen or later in the spring when the soil has dried. Furthermore the bare ground will be prone to soil erosion from rainfall due to its capped and compacted nature. There is an obligation under Cross Compliance to avoid this environmental problem at the risk of financial penalties taken from Single Farm Payments. The Soil Protection Review (part of the Good Agricultural and Environmental Conditions publication) is a process that all farms must carry out and helps producers plan how to reduce soil damage as well as what steps can be

taken to remedy problems such as those caused by a wet maize harvest (DEFRA and RPA,2010).

In areas where harvest is likely to be delayed it would be wise to grow the earliest maturing varieties to try and harvest before soil water levels are renewed in late autumn. Maintaining drainage through proper deep cultivations such as sub soiling and mole ploughing on heavier soils may help prevent soils from becoming waterlogged. Under sowing maize with grass may help to reduce water logging and will provide soil retention once the crop has been removed and thereby reduce surface runoff.

In extreme circumstances where harvesting would do significant damage to the field it may be more cost effective to leave the maize standing and either plough it in to return organic matter to the soil or winter graze it with young stock to recoup some of the costs (Lardner and Pearce,2012) rather than pay to repair the soil through expensive cultivations in the winter or following spring.

Over application of manures

The opportunity presented by the relatively late sowing time of maize coupled with the relatively few other opportunities to apply organic manures in late spring on a livestock farm (due to the risk of contamination of grass silage), plus the lack of awareness amongst farmers as to the nutrient content of manures, has led to the over application of nutrients via organic manures to maize fields in some cases (Withers and Lord,2002, Jarvie *et al.*,2006, Withers *et al.*,2006).

The introduction, and recent expansion, of the Nitrate Vulnerable Zones (NVZ's) plus the considerable work undertaken by projects such as the Catchment Sensitive Farming Initiative(CSF,2012) has increased farmer awareness of the nutrient content of manures.

Surplus nutrients not used by the crop are at risk of loss to the wider environment through water transport to rivers and lakes (surface runoff or leaching) and via gaseous emission (nitrous oxide). The appearance of excessive nutrients in surface and ground water is known as eutrophication and agriculture can contribute to this (Withers and Lord,2002, Jarvie *et al.*,2006, Withers *et al.*,2006). The presence of excess nutrients can lead to rapid algal growth (or blooms) that can have a negative effect on other species, either by outcompeting for resources or through hypoxia (depletion of oxygen in the water, reducing populations of fish and other animals). Agriculture's contribution is a target for reduction (DEFRA,2007). Farms need to assess the nutrient content of slurry and manure and tailor applications to

meet maize requirements as discussed earlier in chapter 4. As maize roots are poor at travelling for P there has been an increase in starter applications of P fertiliser. When organic manures are also used there is the risk of a P supply above the total crop requirement. This surplus is prone to surface runoff into water courses; this is most likely to occur at times of high rainfall when soils are already saturated. Agriculture would benefit from a better understanding of the value of fertilizers in order to use them most efficiently without harming the environment.

Conclusion

Environmental impact of agriculture is something that has come under a lot of scrutiny and it is no different for farms growing maize. Due to the UK's short growing season and maize's late sowing date, the risk of harvesting in wet weather on waterlogged soils is high in several parts of the country. Damage to soil can cause erosion and leaching of soils – something that is to be avoided at the risk of failing cross compliance and thus suffering penalties from Single Farm Payment. UK research needs to highlight and improve the earliness of varieties available to growers so that they can endeavour to grow and harvest a crop before fields begin to return to their water capacity after the summer and autumn months. Furthermore it would be valuable to be able to provide farmers with Ontario Heat Unit data from their nearest weather stations so as to give some indication as to how marginal their particular region is for growing certain varieties – although this will never be truly accurate for specific fields. Over application of manures is an area where farms need more education on the nutrient content of organic manures and the effect this may have should leaching of nutrients lead to water pollution.

Chapter 10 – Conclusions and Research Targets

There is a wealth of information on growing maize published by the scientific community due to its value as a forage of high feeding value and relatively simple agronomy that many dairy farms can grow successfully. However due to the climate of the UK it has only become an established main stream crop in the last 20 to 30 years – consequently the UK based research is also behind that available from the US, Europe and Australia. In many instances the research from abroad can be applied to UK conditions with a good degree of confidence, for example the nutritive value of maize varies by variety but remains similar globally. This means that feeding trials carried out in the US, for example, using 'corn' silage will be useful to researchers and producers in the UK and vice versa.

In the fields of agronomy and pest and disease control, it is more difficult to use research from abroad where climatic conditions are very different to those found in the UK (or elsewhere). It is in these areas where UK research is absolutely essential in order to provide UK maize growers with relevant up to date information. There has been excellent research on agronomy of maize growing in the UK and there are plenty of guides already available to growers – often free of charge. The same is true for guides to dealing with pests and diseases although these are often produced by companies trying to sell products there also are independent guides available. One area of research needed is in the area of reduced tillage methods for maize crop establishment, which has not been researched extensively for UK conditions.

An area of real concern for UK maize growers is the selection of varieties. As the UK is a marginal area for maize growing it is essential that producers have the best possible information on each variety of maize – especially when dealing with early maturing varieties. For a crop as important as maize is to the industry it would be of benefit for there to be yearly trials, akin to those conducted for wheat, of varieties where earliness is recorded alongside Ontario Heat Unit data. In time this would help producers grow a successful crop more regularly as data on required growing days for each variety can be married to sites on farm receiving the requisite growing units.

As the UK climate is seemingly set to continue changing it would be valuable to the industry if Ontario Heat Unit measurements were calculated for sites across the UK. Existing weather station data could well be sufficient to calculate this and it is an area worthy of investigation. As maize growth is dependent on temperature rather than day length and light levels it could be seen that the regional OHU for the UK has been increasing in recent years which could have implications on variety selection – and it would be useful to be monitoring this in the future.

Finally more work needs to be done on precision farming with regards the use of organic manures in the UK. As discussed there is often a surplus of nutrients applied to maize crops which can cause environmental problems. As there is increasing government legislation on this issue it is important that farmers are given the best advice on how to maximize the efficient use of manures, a valuable farm resource. Whilst it is encouraging that the issue is more widely understood through publications such as the Catchment Sensitive Farming Initiative there is still a problem.

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