The design and development of three planters (Marks 1, 2 and 3) to plant daffodil bulbs under agricultural upland grassland and a harvester to collect the above ground biomass.

***D R White[1], I J Loynes[1], S E Cooper[1], K Stephens[2], S Head[2], X Chang[2], M D Fraser[3], H Vallin[3] and J R T Davies[3].**

[1]Harper Adams University, Newport, Shropshire, TF10 8NB, UK.

[2]Agroceutical Products Ltd, Fedwlydan, Glasbury-on-Wye, Powys HR3 5ND.

[3]Pwllpeiran Upland Research Centre, Cwmystwyth, Aberystwyth, Ceredigion, SY23 4AD.

*Corresponding author: drwhite@harper-adams.ac.uk

Abstract

The number of people suffering from dementia is considerable and growing at a significant rate. Alzheimer's disease accounts for between 50 and 75% of these cases. Galantamine is a pharmaceutical compound that has been an approved treatment for Alzheimer's disease since 1998. Galantamine can be synthesised chemically but it is a difficult and expensive process. Producing galantamine from the alkeloid galanthamine extracted from daffodils is more cost effective, but supplies are limited.

Research has suggested that the environmental challenges associated with upland areas trigger a higher concentration of galanthamine in daffodils compared to daffodils grown under lowland conditions. A 4.5 year UK Agri-Tech Catalyst Industrial Research project is investigating daffodil-derived galanthamine production by integrating daffodil growing into permanent upland sheep pasture. The aim is to increase the economic sustainability of hill farming by providing farmers with a high value supplementary daffodil crop while maintaining a traditional farming system.

Machinery is readily available for lowland daffodil production for the cut flower market and for the production of bulbs. Soils are typically deep, fertile and free draining. However, the UK uplands are characterised by low temperatures; exposure to wind; high rainfall; winter snow and frosts; thin impoverished stony soils; a shortage of major nutrients and steep slopes. As part of the research project Harper Adams University agricultural engineers have developed machines for planting daffodil bulbs and harvesting the above ground daffodil biomass in these arduous upland grassland pastures. The planter uses belts to meter and deliver bulbs from the storage hopper to two drop chutes positioned above the purpose built ground opening winged tines. The harvester removes and collects the above ground biomass which is then transferred to sealed containers before being processed.

Keywords: Galanthamine, Galantamine, Daffodil, Upland Pasture, Planting, Harvesting.

1. Introduction

The number of people suffering from dementia is considerable and growing at a significant rate. In 2017, there were estimated to be 50 million dementia sufferers worldwide (Alzeimers Disease International, 2018) and 4.6 million new cases are diagnosed each year. Alzheimer's Disease (AD) accounts for between 50 and 75% of these cases. The U.S. Food and Drug Administration, the UK Medicines and Healthcare Products Regulatory Agency and The European Medicines Agency has approved galantamine as an AD treatment since 1998. Galantamine can be synthesised chemically but it is a difficult and expensive process (Trost and Toste, 2000; Marco-Contelles et al, 2006). Producing galantamine from galanthamine extracted from plants, for example, daffodils (*Narcissus sp*) (Torras-Claveria et al, 2013) is more cost effective, but supplies are limited. The annual global consumption of galantamine is currently constrained to 3-4 t yr^{-1} by existing production levels, but published figures predict the potential global market could be nearer 40 t yr^{-1}. Independent reports project the competitive active pharmaceutical ingredient price for galantamine drugs will remain between £15,000 - £18,000 kg^{-1} in the medium term.

Previous research has suggested that the environmental challenges associated with upland areas (low temperatures; exposure to wind; high rainfall; winter snow and frosts; thin impoverished stony soils; a shortage of major nutrients and steep slopes) trigger a higher yield of galanthamine in daffodils (bulbs and above ground bio-mass) that are grown there when compared to those grown in normal lowland conditions (Department for Environment Food & Ruarl Affairs, 2006). Daffodils grown for galanthamine production, therefore, could offer a novel, high-value crop for upland farmers that will provide an important new income stream, increasing their economic resilience.

Currently, daffodil-derived galanthamine production using normal bulb/flower growing systems requires annual mouldboard ploughing of the soil (with the associated release of greenhouse gases and soil erosion) and strict herbicide regimes to control weeds (with associated impacts on biodiversity). A 4.5 year UK Agri-Tech Catalyst Industrial Research project (commenced March 2015) is investigating daffodil-derived galanthamine production by integrating daffodil growing into improved permanent upland sheep pasture. The aim is to increase both the production of galanthamine and the economic sustainability of hill farming by providing farmers with a high value supplementary daffodil crop while maintaining a traditional farming system. This paper describes the equipment that has been developed for planting daffodil bulbs and harvesting the above ground daffodil biomass in these arduous upland grassland environments.

2. Materials and Methods

2.1 Prime mover.

A range of vehicles, including compact agricultural tractors, all-terrain vehicles (ATVs) and off road utility vehicles, as well as self-propelled tracked vehicles, were evaluated as potential prime movers for both the planting and harvesting operations. Because the production of the daffodils is designed to be integrated within existing pastureland and the required tractive forces needed to pull the planter, a 55 kW tractor was chosen to pull both the planter and harvester.

2.2 Planter.

The aim of the planter was to plant commercially available daffodil bulbs (sizes 10/12, 12/14, 14/16 and 16+) under sloping permanent pasture at rates of 4 to 10 t ha^{-1}. Upland soils are typically shallow and stony with the subsoil containing large stones / rocks (Soil Survey of England and Wales, 1984a; Soil Survey of England and Wales, 1984b). Ideally, daffodil bulbs should be planted 150 mm deep and, in cold climates, the bulbs should be covered by at least 75 mm of soil to protect them from frost.

2.2.1 Row spacing.

As it is not known how long daffodils will remain productive under these harsh conditions when they are harvested each year with limited opportunity to regenerate the below ground biomass, it was decided to plant the bulbs in two rows 800 mm apart. This will allow, if necessary, daffodils to be planted in between existing rows by moving the tractor / planter combination over by “half a wheel-track width”.

2.2.2 Metering mechanism.

Typically, metering mechanisms on bulb / tuber planters consist of either flat belts or cup mechanisms (Bell, 2016). For simplicity, a belt mechanism was chosen but, unlike machines used on flat / slightly undulating ground, a cleated belt (Figure 1) was used to provide traction for the bulbs and provide consistent feed rates when going up and down hill. To give a controllable, wide range of planting densities, a tractor driven hydraulic motor was used to drive the metering mechanism and provide planting rates of up to 10 t ha^{-1}.

(a) Two row planter cleated belts.

(b) Close up of a cleated belt.

Figure 1. Planter cleated belt.

2.2.3 Depth control.

Depth control was via wheels at both the front and rear of the planter. The rear wheels also acted as press wheels to consolidate the loosened sward to give good soil / bulb contact.

2.2.4 Ground opening device.

Upland soils are generally shallow (75 to 150 mm) and have low shear strengths. To minimise the damage to the existing grass sward, a heavy duty plain disc (Figure 2) was used to make a vertical cut through the sward. To minimise draft forces (Godwin and Spoor, 1974) and to allow the sward to remain intact whilst being lifted and then allowed to fall back in its original position once the bulbs had been planted, an opener with a low rake angle was required (Payne and Tanner, 1959). Experiments by Cooper (2015) evaluated a range of commercially available tines. A specially designed furrow opener (Figure 3) was manufactured with the aim of peeling back the sward cut by the leading disc, gently lifting it intact whilst the bulbs were planted before allowing the sward to fall back into place so covering the bulbs.

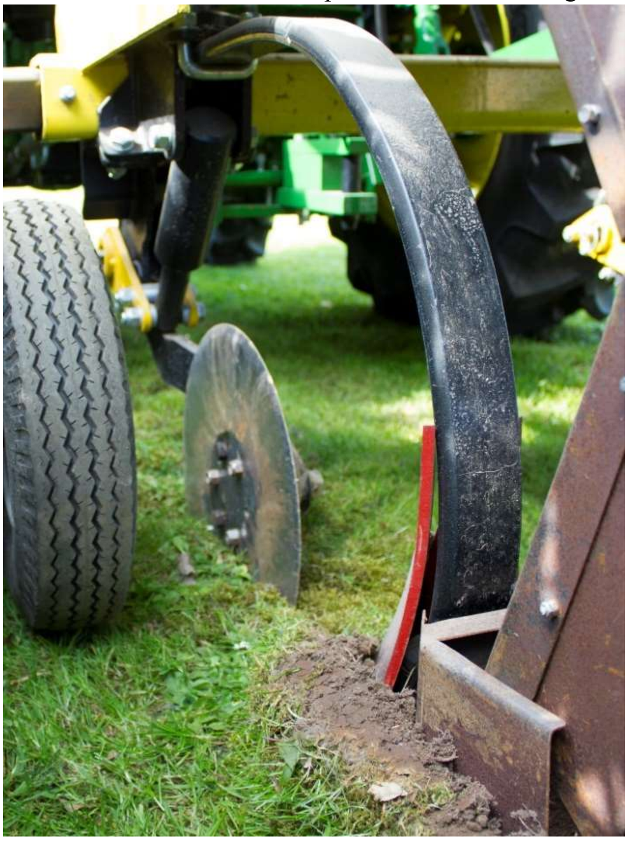

Figure 2. Planter tine and disc unit.

Figure 3. Soil opener.

2.2.5 Frame

Because of the undulating ground profile, local depressions and mounds, and rocks close to the soil surface, an articulating frame was manufactured for the Mk2 two row planter to enable independent movement of the front and rear halves of the planter so improving the depth control.

2.3 Harvesting machinery.

The aim of the harvester is to harvest the above ground daffodil bio-mass and grass leaving “stubble” of between 80 and 100mm and deliver the product into water tight boxes sealed with a lid to prevent external contamination from vermin, birds and weather. These boxes are then transported off site where the material is processed and the galanthamine extracted, before further processing to extract the galantamine.

Typically, above ground bio-mass of agricultural or horticultural products is harvested either by cutting or flailing. A range of commercially available equipment, for example, baby leaf salad harvesters and amenity flail grass collectors were considered as base units. Both of these techniques were evaluated on daffodils in 2016. In order to eliminate the need for additional processing of the harvested bio-mass at the galanthamine extraction phase and reduce transportation costs, flailing was chosen as the preferred method. In 2017, a commercially available flail harvester with a working width of 1.3m was purchased. This enabled two rows of daffodils to be harvested at the same time. Modifications in 2017 and 2018 included changes to the cutting height mechanism (range 0 to 350 mm), modifying the rear castor wheels and the addition of a hopper discharge mechanism.

3. Results and Discussion

The Mk1 and Mk2 planters and harvester have been used to establish and harvest a total of 16 ha of experimental plots at the Aberystwyth University Upland Research Centre, Pwllpeiran, Wales (52.3553° N, 3.8006° W). The project plots are in permanent pasture that ranges from 250 to 430 m above sea level with slopes of up to 27 degrees. The soil is a clay loam with an average cohesion of 22.5 kN m^{-2} and angle of internal shearing resistance of 9.5° and an average stone content of 45% (Cooper, 2015).

3.1 Planting.

The first-year planting (2015) was completed using a single row (Mk1) version of the final machine (Mk2) (Figure 4) using a ground wheel drive and a V-belt driven metering mechanism. A total of 6 ha of plots were planted with size 10/12 and 12/14 bulbs at a rate of 4 t ha^{-1} and rows spaced at 800 mm apart. For the second year, planting rates of up to 10 t ha^{-1} were required with bulbs sizes ranging from 12/14 up to 16+ and the ground wheel V-belt drive system was replaced with a tractor driven hydraulic motor. An additional 10 ha of project trial plots were planted in the second year using the two-row planter as shown in Figure 4.

Figure 4. Mk2 planter at Aberystwyth University Upland Research Centre.

The articulated frame performed well and enabled good planting depth control over the undulating ground profile.

The metering mechanism resulted in the bulbs being randomly orientated between “apex up” and “apex down”. Additional plots and small scale plot experiments in 2016 and 2017 showed that bulbs planted “apex down” emerged up to 2 weeks later than those planted “apex up” leading to inconsistencies in growth stage at harvest. This suggests it may be worthwhile designing a metering mechanism that will plant all the bulbs “apex up”. However, the effects on plant growth in subsequent years is comparatively minimal.

3.2 Harvesting.

To maximise the amount of daffodil bio-mass whilst minimising the amount of grass and soil contamination, the flail height was set to give an average cut height of 100 mm. Cutting daffodils just as they are about / have started to flower (Figure 5) is contrary to normal growing advice which is to leave the foliage to wilt and die back for at least six weeks after flowering before removing it to allow the bulb time to recover ready for flowering the following year (Royal

Horticultural Society, 2018).

Figure 5. 2018 harvest at AU Upland Research Centre.

It is not known at this stage if flailing the bio-mass, rather than cutting it with a reciprocating knife, has any effect on making the plants susceptible to viral and bacterial diseases.

3.3 Future work.

. Future work may include modifying the planter to plant the bulbs "apex" up. Additionally, the harvester may require further modifications to adjust the cut height automatically depending on the ground profile and provide a system for lifting lodged crop that has fallen outside the standard cut width. Harper Adams is also designing and manufacturing a trailed planting machine (Mk3), based on the Mk2 two row planter, but with the bulbs delivered towards the tractor.

4. Conclusions

A planter to establish two rows of daffodils bulbs at 800 mm spacing in permanent upland pasture has been manufactured and a flail harvester has been modified to collect the above ground biomass ready for processing to extract galanthamine

Acknowledgements

The authors would like to express their thanks to the Biotechnology and Biological Sciences Research Council, Innovate UK, Keith Rennie Machinery Ltd, UK and John Deere Ltd, UK.

References

Journal articles:

Godwin, R. J. and Spoor, G. Soil Failure with Narrow Tines. Journal of Agricultural Engineering Research, Vol 22, No 3, p 213-228, 1977.

Marco-Contelles J., Carreiras, M.D., Rodríguez, C., Villarroya, M., and Garcia, A.G. Synthesis and pharmacology of galantamine. *Chemical Reviews* **106**, 116-133, 2006.

Payne, P.C. and Tanner, D.W. The relationship between rake angle and the performance of simple cultivation implements. *J. Agric. Eng. Res.* 4(4), 312-325, 1959.

Torras-Claveria, L.,Berkov, S.,Codina, C.,Viladomat, F., and Bastida, J. Daffodils as potential crops of galanthamine. Assessment of more than 100 ornamental varieties for their alkaloid content and acetylcholinesterase inhibitory activity. *Industrial Crops and Products*. (44). 237-244. 2013.

Trost, B.M. and Toste, F.D. Enantioselective total synthesis of (-)-galanthamine. *Journal of the American Chemical Society* **122**, 1262-1263, 2000.

Books:

Bell, B., 2016. Farm Machinery, 6th edition. Sheffield: Old Pond.

Soil Survey of England and Wales, 1984a. Soils and their use in Northern England. Harpenden: Soil Survey of England and Wales.

Soil Survey of England and Wales, 1984b. Soils and their use in Wales. Harpenden: Soil Survey of England and Wales.

Technical reports:

Department for Environment Food & Ruarl Affairs, 2006. Sustainable production of the natural product galanthamine. Defra project code NF0612. Institute of Grassland and Environmenatl Research, Plas Gogerddan, Aberstwyth SY23 3EB

Theses and dissertations:

Cooper, M., 2015. An investigation into the terramechanics of a prototype daffodil bulb planter. CREST Report (unpublished). Harper Adams University, Newport, Shropshire, UK.

Internet resources:

Alzeimers Disease International, 2018. Dementia Statistics. https://www.alz.co.uk/research/statistics Accessed May 30, 2018

Royal Horticultural Society, 2018. Daffodils. https://www.rhs.org.uk/advice/profile?PID=91 Accessed June 1, 2018.