THE APPLICATION OF HARVESTER-MOUNTED FORAGE YIELD SENSING DEVICES

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SUMMARY

The development and application of precision agriculture technology to forage crops offers scope for improved management practices and targeting of inputs. In particular, the ability to measure forage throughput on a harvester would form the basis for improved management decisions and the ability to exploit precision agriculture technology, including accurate application of forage additives. The aim of this project was to develop a forage throughput sensor and to use that sensor to record yield variability and to accurately control additive application.

Following preliminary trials, a force sensing plate placed in a forage harvester chute was developed and assessed. A very good relationship between sensed throughput and measured throughput was achieved, with regression coefficients of between 0.88 and 0.96 recorded in a series of trials. The relationship was established on a fresh-weight basis. Calibration could present difficulties in practice.

The forage throughput sensor was linked to a GPS positioning system and a modified yield monitor/recording system to facilitate the measurement of yield variability in the field. Considerable difficulties were encountered with compatibility of the various components, including the analysis software. While a forage yield map was created and illustrated the levels of yield variability within a field, the need for simultaneous on-harvester dry matter sensing was apparent.

A throughput-based additive application control system was designed, developed and tested. The unit performed satisfactorily, resulting in less variation in the quantity of additive applied to harvested grass compared to conventional application systems.

In conclusion, there is scope for the application of precision agriculture technology, based on forage yield sensing, on grassland farms. However, there are many differences between the adoption of this technology on grassland farms compared to arable farms. In particular, yield-sensing accuracy is unlikely to be as good, and the need for simultaneous DM sensing is critical. Forage yield sensors will be commercialised soon. There will then be a need to evaluate these systems and the application of precision agriculture technology to grassland systems.

INTRODUCTION

The application of electronics to farm machinery has allowed the adoption of precise monitoring and control functions, which can influence many aspects of machine operation. Initially, electronics were used to monitor and control machine functions to help improve machine efficiency or work rate. More recently, however, electronic systems are being used to measure crop or field variables, such as crop yield, and to control input application. In particular, the development of precision agriculture technology, which measures within-field variability of a parameter like crop yield and uses this information to target input application, has resulted in machine electronics playing a role in management decisions.

To date, the applicability of precision agriculture systems has been restricted to certain crops. The availability of commercial combine harvester yield meters has made the application of precision agriculture systems possible with all cereal crops. Less well-developed yield monitoring systems are becoming available for root and tuber harvesters. Silage is Ireland's largest harvested field crop, with approximately 20M tonnes of grass, harvested from 1.24M ha, ensiled annually (O'Kiely *et al.*, 2000). There are no commercially available yield meters for forage at present. Forage yield sensing research has focused solely on the evaluation of yield assessment systems, particularly in maize forage crops (Auernhammer *et al.*, 1995*;* Martel, 1999). There was little research into the practical application of yield/throughput sensing technology. Some plot investigations indicated potentially high levels of within-field yield variation (Kasper, 1998).

Grass grown for silage is managed differently than cereals and, consequently, the application of precision agriculture technology will be different. The ability to measure the throughput of forage on a harvester would potentially deliver a number of benefits:

- The availability of accurate yield information, when harvesting, would facilitate improved management decisions concerning winter feed budgeting and field management. It would also form the basis of an improved charging system for silage contracting.

- Throughput sensing would allow yields to be mapped and spatially variable grassland management practices to be evaluated.

- The application of additives to forage, based on the instantaneous throughput of grass through the forager, should result in better use of the input.

A programme evaluating the use of precision agriculture type technology on grass for silage was commenced. The objectives of the research reported here were to:

1. Develop and evaluate grass throughput or yield-sensing systems suitable for mounting on a forage harvester.

2. Use a harvester-mounted throughput sensor to measure and map within-field forage yield variations.

3. Develop and assess a throughput-based additive application system.

As each of these objectives required separate research actions, they are presented separately in this report.

1. On-Harvester Throughput Sensing

INTRODUCTION

Grass throughput or yield sensing techniques have received little research compared to similar sensing techniques developed for cereal harvesting. As grass is not considered a cash crop, the perceived need for precision in management is frequently less. The opportunities to assess grass flowing through a forage harvester are less than those available to measure the quantity of grain flowing through a combine harvester. The low density and uneven physical distribution of the grass particles in a forage harvester differ markedly from that of threshed grain flowing through a combine. There are also less opportunities for measurement in the flow path of grass through the forage harvester.

Opportunities for grass throughput measurement are available, and some of these have been shown to have potential as throughput measurement sensors when harvesting maize or whole-crop cereals (Auernhammer *et al.*, 1995). However, harvesting grass from perennial crops is likely to cause greater difficulties, as the delivery of grass from a pre-cut and picked-up swath is likely to be more uneven than from direct-cut maize or whole-crop silage. The aim of the work described here was to design, assess and develop an on-harvester forage throughput sensor.

MATERIALS AND METHODS

Preliminary assessments of two yield sensing techniques were carried out in the work reported here. A precision-chop forage harvester (JF 850) was instrumented to monitor: (i) the opening of the feed rollers; and (ii) the force exerted by the chopped forage in the chute (Fig. 1).

The feed rollers that compress and deliver grass to the chopping cylinder are held against the grass with strong spring pressure. The feed rollers move up and down continuously to accommodate different volumes of grass. It was considered that the displacement of the feed rollers would indicate the level of throughput of forage. Feed-roller position was sensed by recording the force exerted on fixed load cells by springs attached to the moving feed rollers.

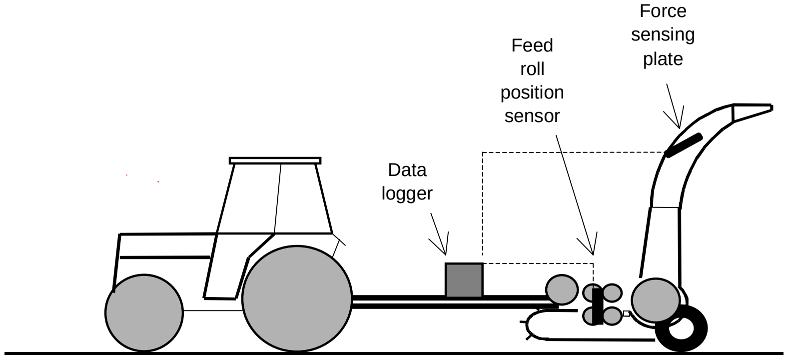

Fig. 1: Location of throughput sensors

Grass is delivered from the forage harvester by the impelling force of the cylinder, which throws and blows the grass through the delivery chute to the trailer. The force exerted by the column of grass being delivered through the chute is related to the mass of grass being propelled. This is the principle used when measuring force in the harvester chute. A rectangular plate was placed in the path of the grass flow in the upper section of the harvester delivery chute. The plate was attached to an externally mounted shear-strain type load cell. To select an appropriate sized load cell, the range of expected force values was calculated mathematically using a simulation model (Alcock, 1996).

Outputs from both these sensors were recorded on a purpose-built electronic data logger that stored integrated readings from each sensor every second. The functional performance of the sensors and of the data logging system was checked out-of-season by chopping silage from an unrolled round bale. All sensors operated satisfactorily, with outputs in the expected range.

Field trials

The performance of the sensing techniques was evaluated in a series of field trials. Grass from small plots (2.1 m x 20-30 m) was harvested by the instrumented forager. The harvested grass was collected by a mobile weighing container, which was towed alongside the harvester. In addition to the two throughput sensors, the harvester was also fitted with forward speed and chopping cylinder speed sensors. Grass throughput was varied by harvesting at different forward speeds. Throughput was calculated from the weight of grass harvested in the plot and the average forward speed as recorded on the data logger.

The field trials were carried out over two harvesting seasons. In Year 1, the first trial evaluated both chute and feed roller sensors, while three subsequent trials assessed the chute sensor only. All Year 1 plots consisted of predominantly perennial ryegrass swards. In Year 2, three further trials with the chute force sensor were carried out. Two of these used grass from predominantly ryegrass swards, while the third had a high content of white clover. Grass yields and dry matter contents were estimated at each site.

RESULTS AND DISCUSSION

The methods used in the trials worked well. A range of throughputs from 4 to 28 kg/sec (14-100 t/hr) was achieved by harvesting at the different speeds. The plot weighing system performed satisfactorily, while the data logging system collected suitable information from all the electronic sensors.

Analysis of the preliminary trial results showed the feed roller position data to be of little value in determining output. There was no clear relationship between feed roller position and forage throughput. It is likely that the uneven feed of grass through the feed rollers resulted in excessive oscillation, which was transmitted to the measurement sensors.

The plate sensor in the chute gave a very good relationship between the force recorded and the measured throughput (Fig. 2). Although these results were from just one grass crop, with measurements at just three forward speeds, the linear relationship recorded with a regression coefficient of 0.96 was very promising.

Subsequent field trials in both years evaluated the force sensing plate only. The results are summarised in Figs. 3 and 4 and Tables 1 and 2. In all the trials, there was a good linear relationship between measured throughput and sensor force. The sensor performed satisfactorily over the range of dry matters normally encountered, as indicated by the results with perennial ryegrass at two different dry matter contents in Year 2. The regression lines are almost indistinguishable. The grass/clover mixture results in much lower force readings at a given throughput but a linear relationship between force and actual throughput was maintained.

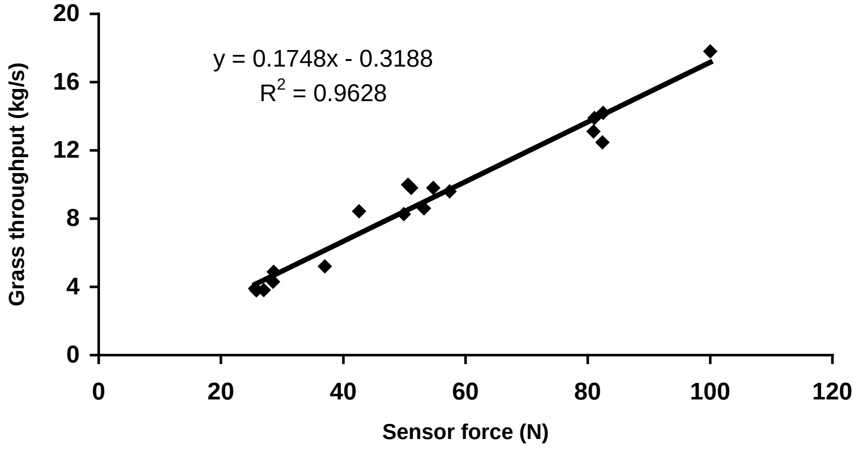

Fig. 2: Throughput sensing calibration – Preliminary

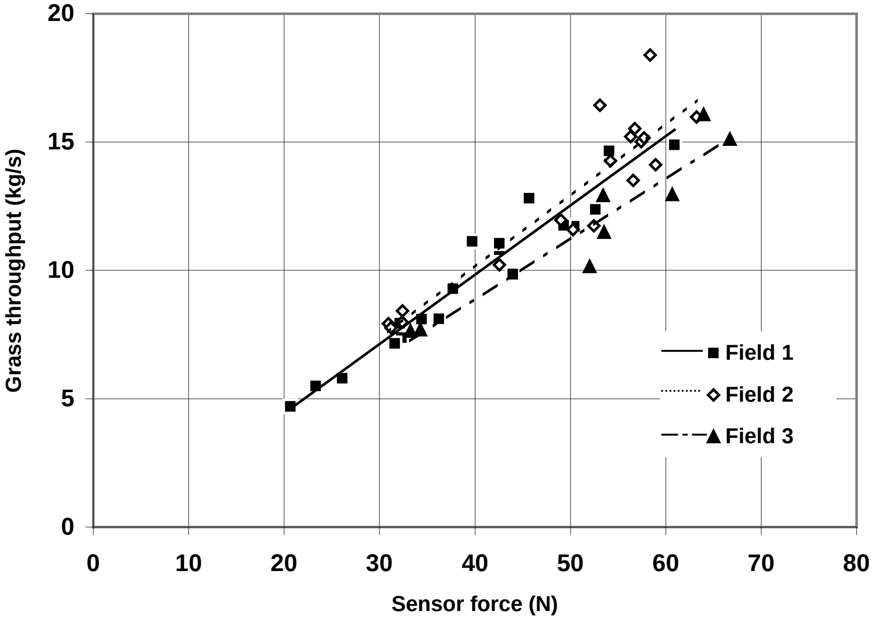

Fig. 3: Grass throughput vs sensor force: Year 1

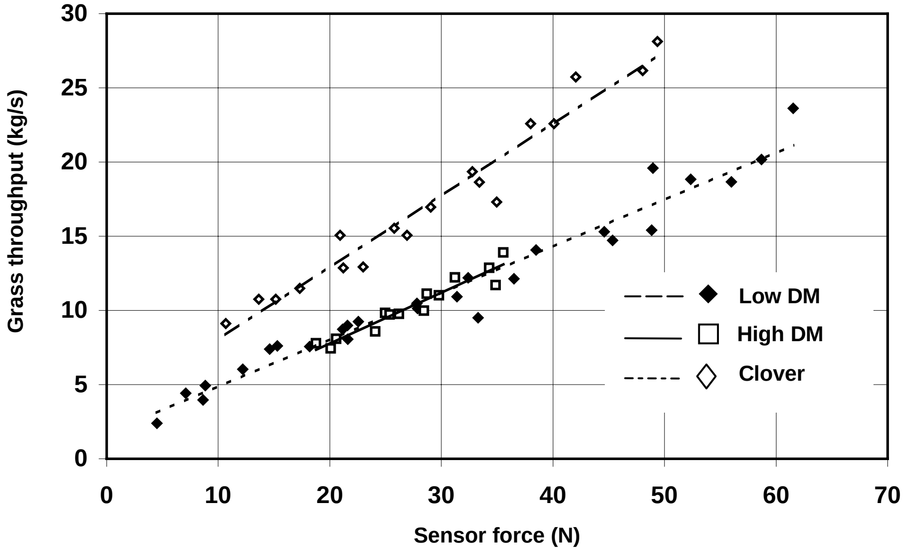

Fig. 4: Grass throughput vs sensor force: Year 2

Table 1: Throughput vs force - Year 1

Site	DM (g/kg)	Regression coefficient		R^2	F-test	d.f.
		Constant	Force			
Field 1	303	-0.95	0.270	0.94	***	19
Field 2	273	-1.02	0.279	0.84	***	17
Field 3	352	-0.62	0.237	0.90	***	7
All fields	300	-0.63	0.261	0.88	***	45

Table 2: Throughput vs force – Year 2

Site	Sward	DM (g/kg)	Regression coefficient		R^2	F-test	d.f.
			Constant	Force			
1	Grass - low DM	190	1.69	0.316	0.96	***	26
1	Grass - high DM	301	0.90	0.343	0.92	***	13
1	Grass - All	163	1.63	0.318	0.96	***	40
2	Clover/grass	228	3.18	0.486	0.96	***	17

Overall, the force sensing plate performed very well as an indicator of forage throughput. However, the sensor predicted fresh weight throughput only. Dry matter content measurement would be necessary to indicate the level of forage dry matter throughput or variation in dry matter yield. It may also be necessary to calibrate the sensor for different grass types, as the physical characteristics of the cut grass influenced the actual response achieved. The opportunities for in-work calibration, where a number of trailer loads are weighed and used to calibrate the system, are not readily available with a silage harvesting system. During cereal harvesting, it is usual to weigh individual loads, thereby facilitating calibration without work interruption.

While a good relationship between force and throughput was recorded, the levels of error with an instrument of this type would be higher than those achieved with grain yield sensors. While it is unlikely that an on-harvester grass yield sensor would ever achieve the accuracy available with grain sensors, further development would be necessary to reduce the level of error. For most applications, an accurate on-harvester dry matter sensor would also be necessary.

2. Use of Throughput Sensor to Produce Yield Maps

INTRODUCTION

The primary use for yield measurement technology in arable farming is in precision agriculture systems. Precision agriculture technology could also have applications in grass or forage production and, consequently, have a role in Ireland's grass-based production systems. Parameters that may prove beneficial to study include crop yield, nutrient status, soil type, presence of compaction etc. While the measurement of the variability of one parameter is unlikely to form a base for variable management in all situations, the mapping of crop yield variation within a field is accepted as the starting point for precision agriculture practices. The objective of the work described here was to develop a yield mapping capability on grassland using the forage yield sensing technique already developed.

MATERIALS AND METHODS

The production of a yield map for any crop requires four different components (Fig. 5):

1. A yield sensor, normally attached to the crop harvester, capable of detecting yield variation at a suitable resolution. The forage harvester force sensing plate developed in this project was used for this purpose.

2. A mobile positioning system that allows the position of a machine in a field to be determined accurately (±3 m). Commercially available global positioning systems (GPS) with differential correction meet this requirement.

3. A data recording system that allows position, yield and any other relevant data to be simultaneously recorded. Data logging/recording systems are available for specific cereal yield monitors.

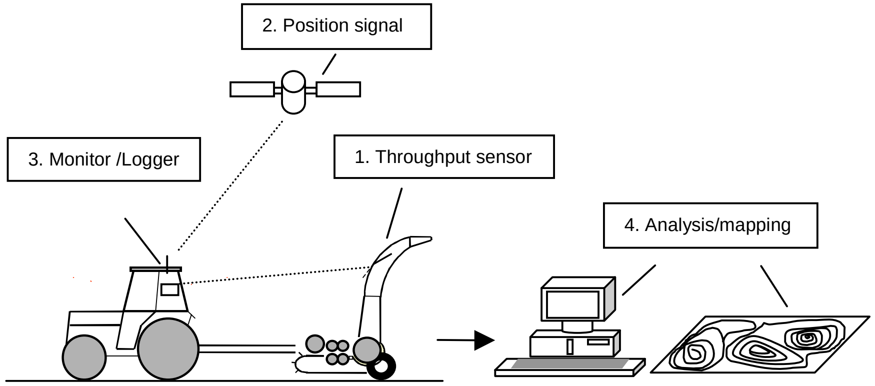

Fig. 5: Forage yield-mapping components

4. Analysis and mapping systems to process the collected data. Computerised analysis systems are available from a number of sources to analyse data from commercially available cereal yield monitors.

The positioning, analysis and mapping systems are available commercially and are applicable to forage yield mapping provided suitable yield data can be collected. The force sensing plate developed in this project forms the basis of a yield meter which can provide yield information on a spatial basis. A necessary component, which required development, was the data recording system. The data handling system must process data from the yield and forward speed signals and record these with appropriate position data provided by a GPS receiver. The data recording system must be robust, as it would be carried on the tractor/harvester and it must have a suitable data transfer method to allow downloading of data for analysis.

Two data recording systems were considered. The first option was to develop a recording system based on a lap-top computer with a purpose-built interface to allow simultaneous capture of the position and yield data. While this option would be flexible, allowing all aspects of data processing to be modified as required, it would have been expensive to develop and subsequent compatibility problems with existing analysis/mapping software would have been inevitable. The alternative approach was to use a commercially available yield monitor/logger designed to process data from a grain yield sensor. This would ensure better compatibility with existing yield analysis/mapping software programs. The unit would be robust and suitable for in-cab fitting. However, the forage throughput sensor data would require significant processing before input to the monitor/logger. This option was selected, as it was considered more beneficial to the future development of forage yield mapping than building a PC-based logger.

A yield monitor/logging unit (LH Agro 565) was procured. This model was selected, as it is designed to process yield data from a load-cell based yield sensor fitted to a combine grain elevator. GPS positioning data, forward speed and elevator speed signals were also processed by this unit to generate a data output which could be further processed to generate management (e.g. field yields, etc.) and site specific (e.g. yield map) crop and field information.

Outputs from the forage yield sensor, chopping cylinder, speed sensor and forward speed sensors had to be modified to provide a suitable data format for the monitor/logging unit. Extensive electronic processing of the yield sensor signal was necessary to simulate the pulse type signal generated by a combine elevator impelling grain onto a cereal yield sensor. A programme of laboratory and field test runs was undertaken to verify the correct functioning of the unit.

Laboratory and field test runs

During the laboratory test runs, a field harvesting routine was simulated. Electronic signals, similar to those from the machine sensors, were inputted in a pattern simulating field harvesting. Output data from these test runs, as presented on the instrument and as analysed by proprietary software and by spreadsheet analysis, was examined.

Following the laboratory tests and preliminary checking in the field, the system was evaluated during a grass harvesting operation in two fields. A low yielding, second-harvest grass crop was used. The throughput sensor was fitted to a trailed precision-chop harvester (JF 850), along with forward speed and chopping cylinder speed sensors. The tractor cab housed the yield/monitor logger, GPS signal receiver and harvester signal-processing unit. Each field was harvested in a normal harvesting pattern, with the data-logging unit operating continuously. Yield and position data were processed and recorded at one-second intervals on a microchip memory card. All trailer loads of harvested grass were weighed using a conventional weighbridge and sampled for grass dry matter content.

RESULTS AND DISCUSSION

Following extensive signal processing to enable the yield monitor/logger to use the outputs from the forage harvester sensors, the yield recording system allowed all necessary inputs to be recorded in a form suitable for subsequent analysis.

The laboratory test runs highlighted problems with data interpretation, in particular discrepancies in the values calculated from different analysis techniques (Table 3). Three analysis methods were examined across four different test runs. The large discrepancies in Runs 2 and 3 were caused by the proprietary software’s failure to recognise high forage yield values logged on the memory card. The difference in total run yield between the ‘instrument summary’ and the other two methods in Runs 1 and 4 was caused by differences in the data processing methods used. The results of these laboratory trials highlight the potential difficulties that can arise with different data analysis systems. The necessity for a robust and transparent data handling system, which produces results that can be verified by a calibration routine, is evident.

Table 3: Yield discrepancies from analysis techniques – laboratory tests

Data sample	Total run yield (kg)		
	Instrument summary	Memory card summary	Spread-sheet analysis
Run 1	1588	1005	1005
Run 2	4466	112	112
Run 3	1519	380	380
Run 4	759	689	689

The data from the field trials showed similar interpretation difficulties. In the Yard Field, the total field yield as measured on the weighbridge and as calculated by three different analysis methods is given in Table 4. The ‘spreadsheet analysis’ total yield figure was within 5% of the yield recorded on the weighbridge. This spreadsheet analysis was the most transparent, as it simply calculated the yield from the raw data. The two other analyses, ‘Instrument Summary’ and ‘Farm Works’ summary gave greater errors.

Table 4: Total yield figures – Yard Field, 1998

Data source	Total yield (t)
Conventional weighbridge	122.5
Spreadsheet analysis	117.6
Instrument summary	141.1
‘Farm Works’ field summary	100.6

The yield data from the second field (Lawn Field) was analysed and mapped using ‘Ag Leader’ analysis and mapping software. The second harvest crop was low yielding (3.5 t DM/ha), as there was a soil moisture deficit during the growing period. Soil moisture deficits usually contribute to yield variation because of differences in soil water availability. Recorded variations in fresh yield were extensive, with yields varying from 1.7 to 20 t/ha (Fig. 6). For precision agriculture purposes, dry matter yield figures are necessary. There are two sources of error in a yield map based on fresh weight yield values:

(i) There may be inherent variations in DM content of the crop that would not be noted.

(ii) In a forage harvesting situation the crop dry matter may change significantly as the crop is being harvested.

The data from the Lawn Field was corrected for the change in dry matter over the harvesting day by using the measured dry matter content values from individual trailer loads to determine the forage dry matter yield. These figures indicated that, as the day progressed, dry matter content increased significantly. Consequently, when the yield data was corrected for this drying effect, the pattern of yield variation was altered (Fig. 7), with less of an apparent yield reduction in the left to right direction on the map. The remaining yield variation corresponded well with the visual appearance of the crop.

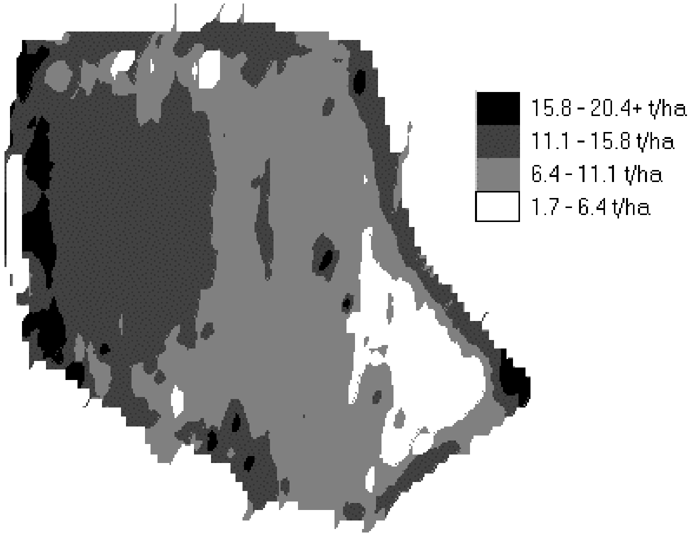

Fig. 6: Lawn Field – fresh weight yield variation

The work in this section of the project outlined the feasibility of measuring, analysing and mapping yield variation using the forage throughput sensor developed in this project. Two significant deficiencies were identified. The need for a compatible logger/monitor and, in particular, analysis/mapping software, that is compatible with the forage data collected, is clearly evident. It is likely that any commercial development would overcome this problem. The most significant problem with grass yield mapping is dry matter content variation. Some of the factors that influence yield variation may also affect dry matter content. Areas prone to drought effects, for example, may have a very low yield on a fresh weight basis but, because of drought, dry matter content in these areas may be higher, resulting in a greater yield of dry matter than indicated by the fresh yield results. On-harvester dry matter sensing would greatly enhance the usefulness of the field yield data.

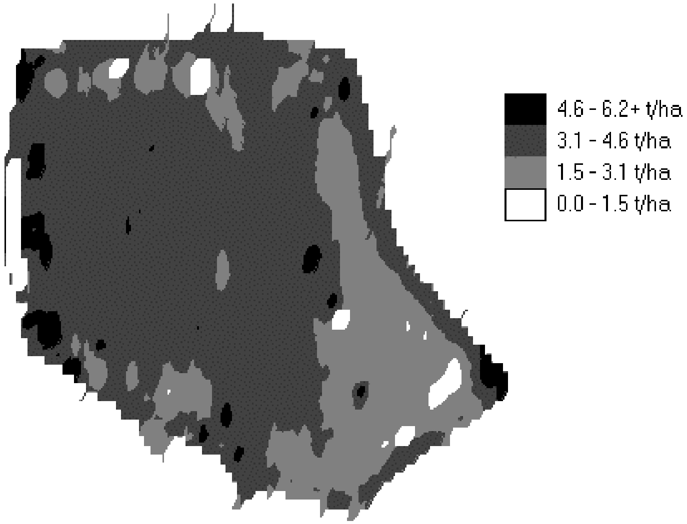

Fig. 7: Lawn Field – DM yield variation

3. Additive Application System

INTRODUCTION

Additives are applied to forage during harvesting to aid preservation and/or to enhance the nutritive value of the ensiled forage. It is normal practice to prescribe additives at a rate based on the fresh weight of the harvested forage, e.g. 2.5 litres of additive per tonne of forage. Additives are normally applied using a liquid or powder applicator with an adjustable flow rate. To achieve the desired application rate, an estimate of the crop yield is required, along with harvesting rate and applicator flow rate information. The calibration procedure is slow and tedious. In practice, it is rarely carried out in full, resulting in poor application accuracy. Variations in harvester throughput add to application inaccuracy. Yield variation within fields and changes in harvester speed are common causes of throughput variation. The satisfactory development of a harvester-mounted forage throughput sensor offers scope for the development of a throughput-based additive application system. The objective of the work described here was to design, develop and test an additive application system where the application rate is controlled by forage throughput as measured on the harvester.

MATERIALS AND METHODS

System design

The control system used the signal from a throughput sensor on the harvester to control the flow rate of the additive, to give a constant rate applied per unit weight of forage harvested. The key components of the system are: a grass throughput sensor in the harvester chute; a control unit fitted in the tractor cab; and a variable speed applicator pump fitted to the harvester (Fig. 8). An analogue voltage signal from the throughput sensor controls the application pump output using a PWM (pulse width modulation) technique to vary pump speed. A closed-loop, proportional-control system compares pump output with the desired output (as determined by the application rate setting) and adjusts the pump speed accordingly. The analogue feedback signal within the control loop is provided by a F/V (frequency to voltage) converter on the application pump to measure rotational speed. The field operation of the unit is straightforward. The desired application rate is set and all other functions including on/off switching at the headland are effected by the control unit.

Test programme

The aim of the test programme was to determine if the additive application rate was satisfactorily controlled by the sensed grass throughput. The control system was fitted to a trailed precision-chop forage harvester (JF 850), which was powered by a 93 kW tractor. A series of test runs was carried out using a high-yielding second harvest, perennial ryegrass crop (26.2 t/ha, 240 g/kg dry matter). Throughputs were varied by harvesting test strips of grass at various forward speeds. A 60 m x 2 m swath of grass was harvested for each test run. The grass harvested in each run was weighed. Forward speed of the harvester was measured with a radar unit mounted on the tractor, allowing throughput to be calculated. Forward speeds in the range 3.8 to 9.6 km/h were used to give a variety of harvester throughputs. The liquid output from the additive applicator was collected at the end of each test run and measured volumetrically.

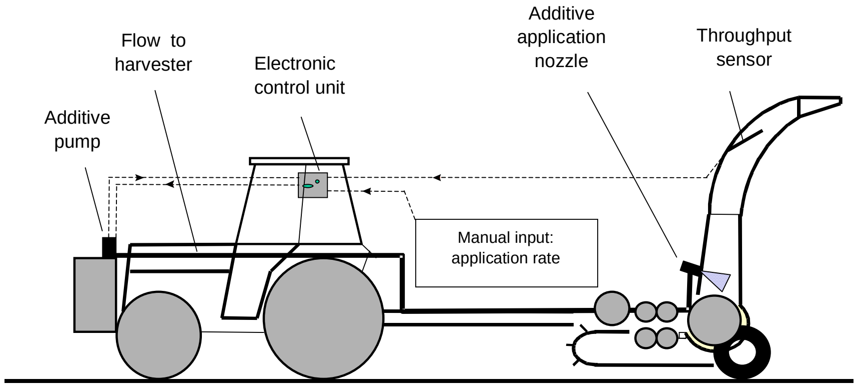

Fig. 8: Schematic of additive application system

RESULTS AND DISCUSSION

All aspects of the control system operated satisfactorily, with the pump on/off status and output satisfactorily controlled by the forage throughput sensor.

The results of the test series are illustrated in Fig. 9. There was a good relationship between grass throughput and additive flow rate as indicated by the linear regression line with an R^2 value of 0.92. The theoretical ideal application response is indicated as a hatched line on this graph. The results show that the system was satisfactorily controlling application flow rate using throughput, as sensed by the chute-mounted yield sensor, as the control factor. To determine the effects of the control system on the evenness of additive application, the level of variation in application rate, with and without the control system working, was assessed using the test run values. With the control system in operation, the variation in the rate of additive applied per tonne of grass harvested was low, as indicated by a coefficient of variation of 0.12. If the pump was set at a constant flow rate without the control system in operation, the coefficient of variation using the test plot data would have been 0.41, indicating very high levels of variation in the rate applied per tonne of grass.

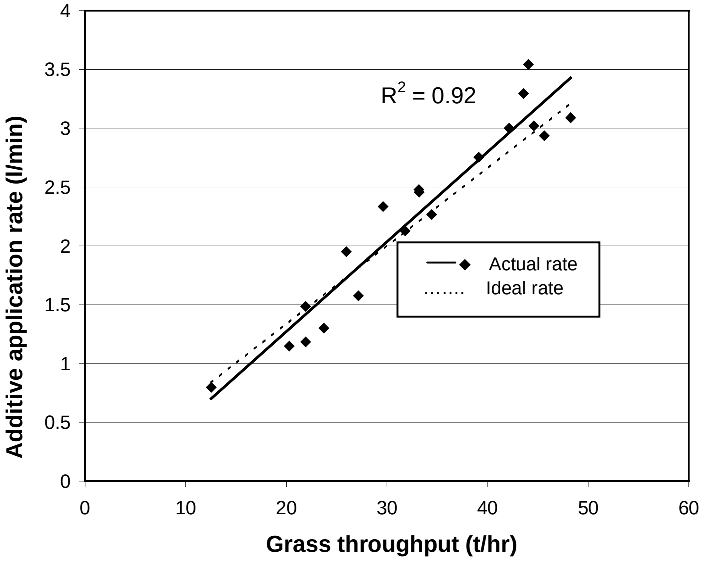

Fig. 9: Additive application rate vs grass throughput

The throughput-based additive application control system satisfactorily controlled application rate. It effectively eliminates the need for manual yield measurement and calibration, and ensures that additive is only applied when grass is flowing through the harvester. The system results in less variation in the quantity of additive applied per unit weight of grass harvested than conventional application systems.

FUTURE DEVELOPMENTS

Since the commencement of this project, there has been considerable research into on-harvester forage throughput sensors by self-propelled forager manufacturers. While none of these has yet reached the market, it is likely that prototype systems will be available within the next one to two years. Recent research on mobile NIR grass dry matter sensors is also showing promising results (Paul, 1999; Martel *et al.*, 1999). Further research by Teagasc in this area will be considered when commercially produced equipment is available.

CONCLUSIONS

- The potential benefits from the development of an on-harvester forage throughput sensor include: the provision of improved information for management purposes; accurate additive application; and the opportunity to exploit the benefits of precision agriculture on grassland farms.

- The novel forage throughput sensor developed in this project performed satisfactorily, giving a good indication of actual grass throughput, and therefore yield, on a fresh weight basis. While good correlation was achieved between the sensor output and weighed yield, the level of accuracy achieved is unlikely to match that of commercial cereal yield sensors because of the physical nature of the chopped forage. All sensors of this type require calibration. The opportunities for regular calibration, by weighing trailer loads, are not readily available during the normal forage harvesting routine.

- The development of the forage yield mapping capability highlights the potential for applying precision agriculture technology on grassland farms. The need for the development of integrated sensing, data logging and analysis packages is clear. The yield sensor’s usefulness is currently limited by the inability to simultaneously measure forage dry matter content.

- An improved additive application system, which uses sensed forage throughput to control the additive application rate, eliminates the need for yield measurement and calibration and would result in less variable application. The forage throughput sensor signal is satisfactory for this purpose, as additives are applied at a rate depending on the fresh weight of the forage.

- Developments in forage yield sensing technology are occurring in the commercial sector, with prototype systems likely to be available in the next 1-2 years. Dry matter sensing technology is also developing. These systems and their integration with analysis packages will need to be evaluated. In particular, the concept of precision agriculture on grassland will need to be assessed and developed. The opportunities for exploitation of this technology, and the likely benefits that will accrue in grassland, are different than those in arable cropping.

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