

Advances in Labour and Machinery Management

Godwin, R. J.

Cranfield University, Cranfield, Bedfordshire, MK43 0AL, UK

e-mail of corresponding author: r.godwin@cranfield.ac.uk

SUMMARY

This paper reviews some recent developments in labour and machinery management in the arable sector principally from work conducted by Cranfield University. It considers the techniques for reduced cultivations and minimising soil compaction including methods to control field traffic and improvements to the management of soil and crop variability by reporting on work for onions and seed potatoes. Developments for “on the go” monitoring of bale quality and those for mechanical weed control are reported. A brief synopsis of the current commercial status of telematics to monitor performance of field equipment is provided alongside that reporting on recent developments to improve traceability systems to ensure crop quality.

1. INTRODUCTION

This paper reviews a number of recent developments in labour and machinery management. These include:

1. Reduction of labour and improved mechanisation management from reduced tillage and compaction alleviation.
2. Results from development in controlled traffic systems.
3. Mechanisms to control the seed spacing to influence the size quality of onions in fields with varying soil conditions.
4. Mechanisms to control intra-row weeds in high value vegetable crops.
5. Developments in telematics for remote monitoring of machine performance.
6. The use of RFID tags and the related architecture for the development of traceability systems in crop production to ensure crop quality, including the development of standards for system integration between key stakeholders in the food chain.

2. REDUCED TILLAGE AND COMPACTION ALLEVIATION

The cost of tillage operations is a vital component of farm profitability and recent years have seen a significant move to reduced tillage systems, where the depth of work (Figure 1) and tine rake angle (Figure 2) have a very significant effect upon tillage forces and work rates. There are, however, a significant number of other factors that have to be taken into account (Table 1), together with the costs of herbicides and of improved agronomical decisions. The data in Figure 3 compare four different tillage systems and show that farm size has a very dramatic effect. Faster shallow mouldboard plough systems can be particularly effective for smaller farms. The main conclusions from this figure are summarized in Table 2.

The data in Figure 1 indicate how the horizontal (draught) force increases at an increasing rate for a 90° rake angle tine operating in uniform soil conditions. The major practical considerations from this are therefore: (i) do not work the equipment deeper than necessary, and (ii) that small reductions in working depth can make a very significant difference to the magnitude of the horizontal (draught) force.

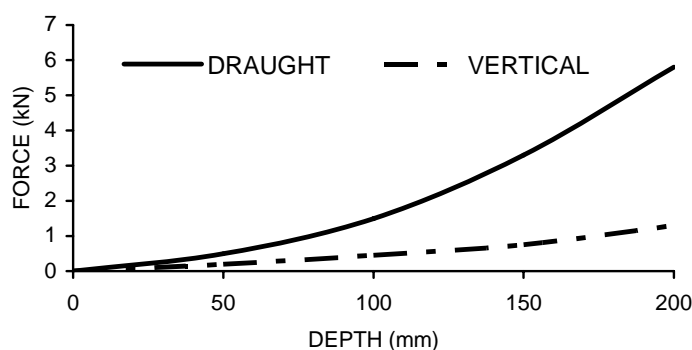


Figure1. The effect of tine depth on implement forces.

After: Godwin and Spoor (1977)

Figure 2 shows clearly how both the horizontal (draught) and vertical forces increase with rake angle. The data also clearly demonstrates that for low draught and good penetration implements should be designed with a low rake angle, this is generally the case for most commercial implements designed for primary tillage. The results from Wheeler and Godwin (1996) for tillage tines operating at speeds up to 20 km/h show that whilst the horizontal (draught) forces increase almost linearly with speed, they do so at a relatively low rate, i.e., where the draught force at 20 km/h is twice that at 2km/h. These principles apply for both individual tillage tools of the now more commonly available “one pass” combination implements. Therefore there is much to be gained from shallower faster machine operations.

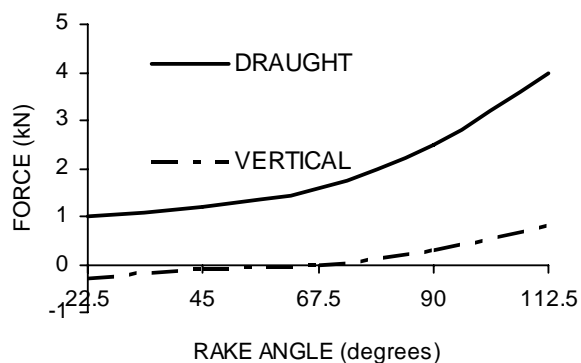


Figure 2. The effect of rake angle on implement forces.

After: Godwin and Spoor (1977)

Table 1. Factors influencing system costs

1. Farm size: annual cropped area.
2. Average tractor size: power availability.
3. Labour availability: can tillage be started before harvest is finished?
4. Local climate: number of working days and the weather conditions.

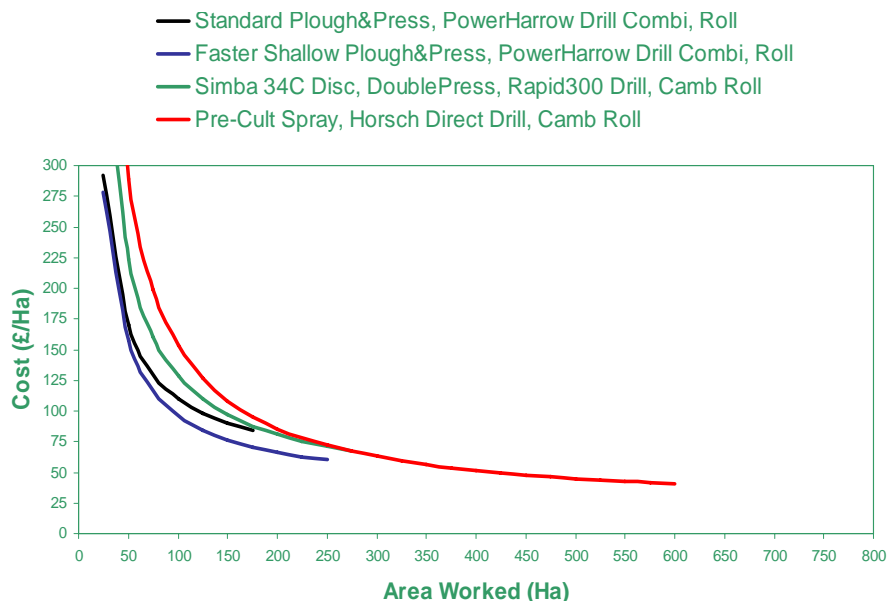


Figure 3. Comparison of the effect of tilled area on the costs of tillage for a range of systems within a 35 day working period.
After: Saunders (2002)

Table 2. Conclusions from system cost analysis

1. Shallow plough c. £20/ha cheaper than standard plough
2. Standard plough cheaper than disc & direct drill at areas less than 170ha for 35 day limit
3. Shallow plough cheaper than disc and direct drill at areas less than 320ha
4. Disc and shallow plough system cover a similar area in 35 tillage days
5. Work rates of direct drill c. 2 x shallow plough and disc and c. 3.5 x standard plough
6. Approximately 2/3 of the tillage cost is the capital cost of equipment (£50/ha)

The management of tractors and harvesting equipment is vital to the effectiveness of the subsequent tillage operations. Smaller increases in soil bulk density, the maintenance of continuous channels and the reduced depth of compaction all assist in reducing the tillage energy needed to establish the following crop. The laboratory study data in Figure 4 show significant reductions in soil deformation as a result of reduced tyre inflation pressures and rubber track systems for tyre loads of 10.5 and 12 tons.

The costs of compaction alleviation (c. £50/ha) are significant and plans should be carefully considered before work is undertaken. These should consider the use of a spade to examine the depth and extent of compaction as a first step. Then consider targeting the work on headlands and tramlines, albeit there is value in leaving “semi permanent tramlines” undisturbed for their duration. Other data showed the benefits of a compact subsoil layer to support the load of combine harvesters; this data revealed that the load transmitted by tracks is supported by the compact layer whereas that from the tyre at 2 bar inflation pressure forced the compaction to a greater depth.

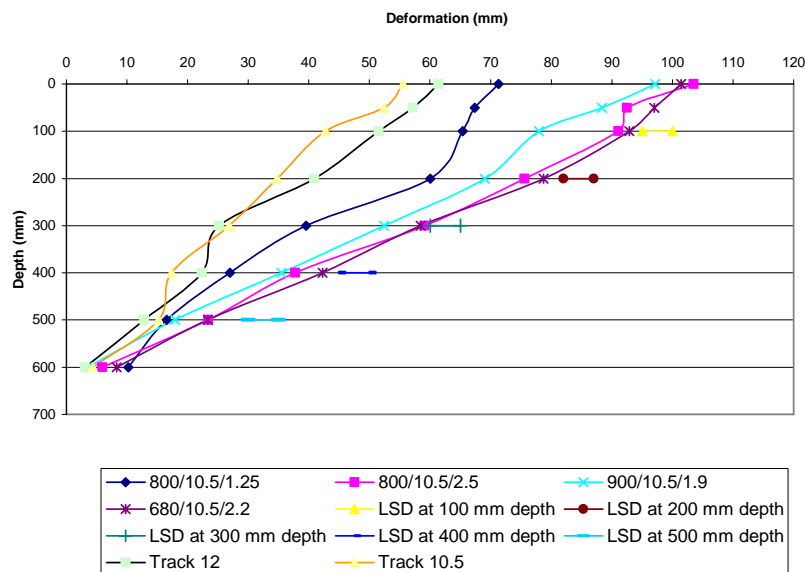


Figure 4. Comparison of soil deformation under a range of tyres and a rubber track. After: Ansorge and Godwin (2006)

3. CONTROLLED TRAFFIC

Controlled traffic or bed management systems have been used by specialist growers of high value crops for many decades. This was reintroduced by the National Tillage Machinery Laboratory in the USA and at a similar time in the UK by the Scottish Centre for Agricultural Engineering and Cranfield University at Silsoe for potatoes and sugar beet respectively. Tullberg and Murray (1986) and Tullberg et al (2003) and their associates realised the potential for this in Australian wheat production, where the wheel spacing of the tractor could be extended to 3 m without violating road traffic restrictions. The purpose of extending the tractor track width is to minimise the number of wheel passages in the field which result in damage from soil compaction. The extension of the wheel centres to 3 m was at the farmers own risk as the operation violated the tractor manufactures warranty. In 2003, however, John Deere lifted this restriction for their 8520 tractors which are equipped with independent link suspension for the front axle. This was good news for the farmers who did not have to take their equipment on the public highway or where there are no legal restrictions to vehicle width. To enable these to be circumvented, Chamen (2006 and www.controlledtrafficfarming.com) and his associates are investigating an adaptation of the principle where combine harvester wheel marks are managed at 3 m centres and all tractor operations work from a parallel set of wheelings at centres either 2 m or as wide as possible apart. Many alternative configurations are possible; however, the favourite option at the current time is called the “OutTrac” where the combine wheel marks are positioned outside those of the tractor, as shown in Figure 5. Whilst this initially appears as if much of the field will be non-productive, the crop is sown over all but the central tractor wheel marks which are used as the tramlines of agrochemical application, as is commonly practiced at the current time in much of Europe. The establishment of the parallel tractor wheel marks is significantly improved by the use of real time kinematic global positioning systems linked to the tractor steering system (e.g. Autosteer (<http://www.123farmworks.com/trimble.htm#autop>)) which positions the tractor to within +/- 20 to 30 mm of the desired course. This has proven to be of value in the production of high value vegetable crops, such as brassica and spinach, in the U. K and the Netherlands, as shown in Figure 6 (Vermuelen et al, 2007).

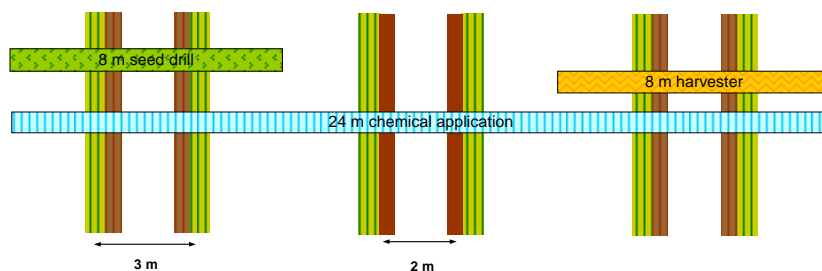


Figure 5. “OutTrac” controlled traffic concept for arable crops with 2 m tractor wheel centres, (outer vertical bars represent tire tracks of combines and the inner vertical bars for tractors either planting seeds or applying agrochemicals), After: Chamen (www.controlledtrafficfarming.com)



Figure 6. Controlled traffic system for high value vegetable production using RTK-GPS and 300 mm wide rubber tracks. Track positions are at 3.15 m centres. After: Vermuelen et al, (2007)

4. ONION SIZE AND QUALITY

Studies by Maguire et al, (2003) showed the potential to improve the uniformity of onion sizes to meet the size quality standards set by the supermarkets, where ideally the size should be a near uniform 50 to 60 mm diameter. A grower had identified that in a number of his fields there was a significant variation in onion size, where onions grown on sandy soils were smaller than average and those grown on clay soils were larger. This was due to variations in soil texture and water holding capacity of the soil. Preliminary agronomic investigations had identified the optimal seed rates for each soil type as shown in Figure 7. The requirement was to provide a seed space controller that would increase the spacing for sandy soils and decrease the spacing for the clay soils. This was achieved by adapting the seed spacing of a precision drill using a planter controller operating from a terminal in the tractor cab, as shown in Figure 8. The seed rate was varied from 370,450 to 543,620 seeds per ha when traversing from the lighter sandy loam to the heavier clay soils. The Fieldstar terminal was provided with an application map based upon the soil texture/water holding capacity of the fields.

The results of this development significantly reduced the variation in onion size range; unfortunately no grade size analysis was conducted but the grower reported a significantly greater proportion (approximately 30% extra) of the crop being sold into the premium target market. This is an excellent example of where the principles of precision agriculture influenced the simple quality indicator of crop size.

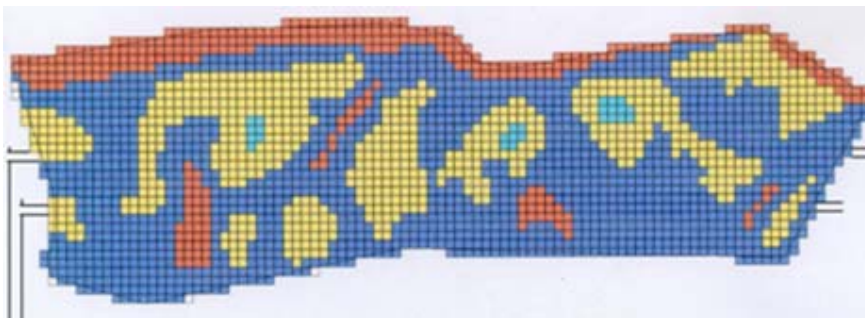


Figure 7. Seed rate application map, as influence by soil type. Red 543,620 seeds/ha, blue 494,200 seeds/ha, yellow 444,780 seeds/ha and light blue 370,450 seeds/ha. Grid size 10m.
After: Maguire et al, 2003



Figure 8. Variable rate onion planting. After: Maguire et al, 2003

5. MECHANICAL WEED CONTROL

Significant development has taken place to improve the precision, reduce the cost and provide environmentally sustainable mechanical weed control systems for high value row crops. Work by Tillett et al, (2002) and Tillett and Hague (2006) have shown the potential of the use of vision systems for the identification of crop rows and plant spacing and the separation of weeds from crops. This has been fundamental to many of the more recent developments. Work at Cranfield University at Silsoe by Pullen and Cowell (2006) used a simple tine to cut a furrow in the field at the time of crop establishment. A furrow follower was attached to the weeder frame to steer the mechanical weeder at high speeds (c. 20 km/h) in subsequent operations. This provided a relatively low cost solution for inter row weeding but required a targeted band spray for the intra-row weeds. Both these developments provide cost effective solutions for controlling inter-row weeds. The mechanisms for addressing the solution to weeds in the intra-row areas were recently addressed by the work of Home (2003). He showed that both root cutting and weed burial were significant methods of suppressing weeds and went on to develop a novel sweep device where the width of the sweeps increased to cut the intra row weeds between the plants and retracted when plants were sensed. The major limitation to this type of device arises from the problem that the mechanism, whilst driven by a rotating cam, causes the sweeps to reciprocate. In an attempt to overcome this issue recent work by Dedousis et al, (2006a and b) has developed a rotating hoe that is constructed from a disc with a 130° sector removed as shown in Figures 9 and 10. The disc is rotated at speeds to compensate for the variations in plant spacing to align the cut out section to correspond with the plant (Tillett et al, 2007). The disc has a sufficiently large diameter and is positioned so that the intra-row weeds are cut at a depth of approximately 20 mm.

O'Dogherty et al, (2007) give a detailed analysis of the kinematics of this mechanism. Preliminary field results have shown this to be very effective.

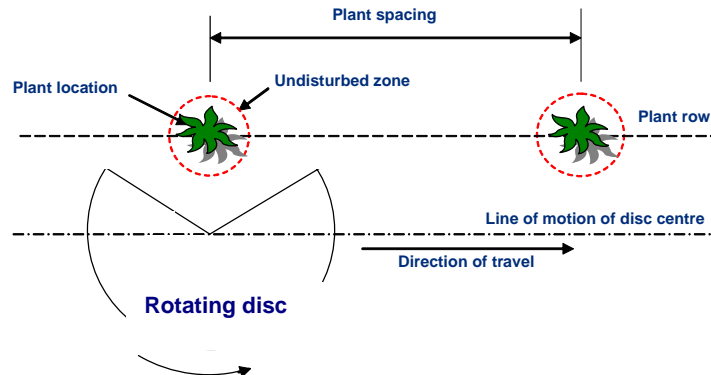


Figure 9. Rotating disc intra row weeding mechanism.
After: Dedousis et al, (2006b)



Figure 10. Prototype single row rotating disc hoe.

The full economic costs of this system is compared to alternatives in Figure 11 which clearly show the advantage of this equipment when compared to both hand weeding and inter row and hand weeding for organic produce and significant savings at areas greater than 50 ha in comparison to agrochemical sprays.

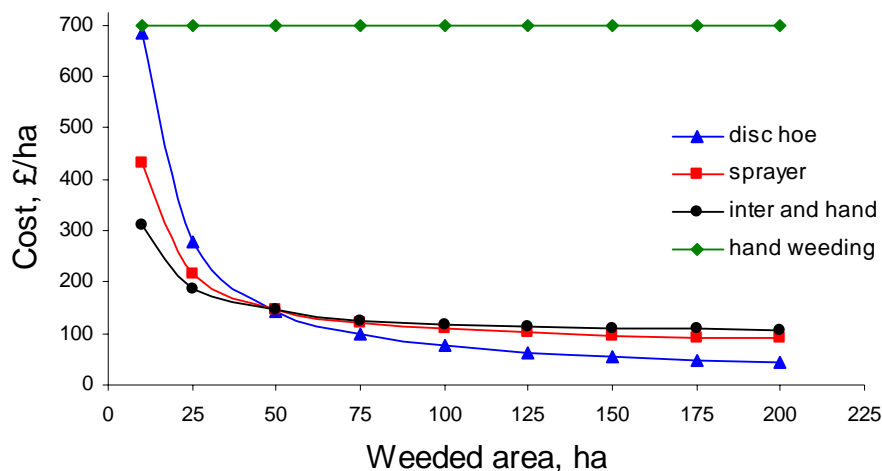


Figure 11 Comparative cost of four different weed control strategies, six men hand weeding (◆); rotating disc hoe (▲); mounted sprayer (■); and inter-row and hand weeding combination (●)

6. TELEMATICS

The past few years has seen a significant rise in the use of diagnostic systems for fault detection in the service of farm machines following the practices used in the automotive industry. In the recent past, Claas (www.claas.com) has taken this one stage further with the introduction of a “Telematics” system which uses an on board data logger to record information from the CAN BUS at 15 second intervals. This information is stored on a PCMCIA card and every 15 minutes this is transferred via mobile telephone modem to the internet, where it is stored by a secure sever which can be accessed and analysed by the farmer, service engineer and manufacturer.

The output of this system can provide information on:

1. the operational performance of the machine, which is valuable in benchmarking output against potential to maximize productivity,
2. the location of the machine such that the farmer and drivers of the tractor/trailers and trucks for crop transport, the factory and the service engineers know the location of the combine harvester. This can be linked to Google Earth such that annotated aerial photographs can be given to drivers unfamiliar with the field locations,
3. the status of the harvester, to be automatically communicated to the trailer/truck,
4. the results of a remote diagnostic check, such that service engineers can be alerted to reduce the down time and carry the correct spare parts.

This system shows the future direction when fewer staff are employed, machine capacity grows and the cost of down time becomes prohibitive in terms of operational efficiency, cost and ultimately crop quality. This may not be critical for grain quality, but it does provide the potential to maintain quality for crops such as “garden peas” and other time dependant vegetable crops.

7. TRACEABILITY

Recent food scares such as those where: 1. non-genetically modified maize for human consumption was contaminated with genetically modified material designated for animal consumption and 2, the contamination of spinach with *e-coli* in California indicate that product tracking and traceability should be a major research focus, particularly to provide the tools on-farm to initiate the process.

The work of Watts et al, (2003), and Watts (2004) clearly identified in on-farm studies that Radio Frequency IDentifer (RFID) methods were superior to bar codes in the field identification of agrochemicals and that this information could link to the approved product data bases for agrochemicals and pesticides held within the farm/tractor/sprayer computer systems. Further studies by Peets et al, (2007) have developed the structure of the RFID label data and they have developed a more sophisticated architecture which links the field application rate recommendations of the agronomist to the precise identification of the agrochemical, using national agrochemical databases and the measured application of agrochemicals to on-farm data bases, as shown in Figure 12. This also accommodates details on the country of registration, registration number, container size, specific gravity of the agrochemical and a digital signature to verify the integrity of the data and provide further security.

To achieve these aims special monitoring equipment is needed where agrochemicals are taken into the sprayer. Watts (2004) suggested that this be undertaken gravimetrically to accommodate the wide range of agrochemical packaging from a few grams to 300 kg. Current work at Cranfield University at Silsoe is developing the hardware and software systems to integrate this to the CAN BUS system mounted on the tractor/sprayer.

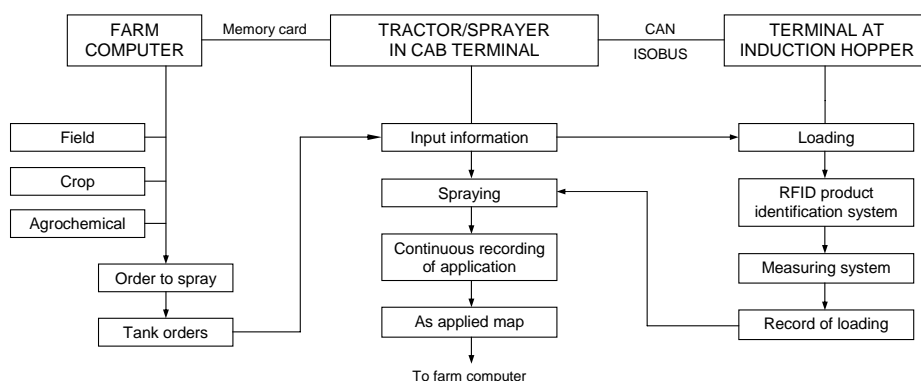


Figure 12.

outline of a data flow chart for a farm traceability system. After: Peets et al, (2007)

It has been recognised that there are many stakeholders in the development, implementation and acceptance of traceability systems. To this end Gasparin et al, (2007) have conducted a series of semi-structured interviews with representatives of all concerned ranging from: farmers and growers, agrochemical companies, software and hardware providers, food and environmental agencies, food retailers and supermarkets. The key findings of this are that all are in favour of such developments as they may provide enhanced food standards, environmental management and commercial market advantage. Key issues are that the systems be cost effective, avoid the labour required for manual entry of data and that the supermarkets only need to work with a limited amount of data, but need access to further details only as and when required. Currently the economic criteria for these systems are being

developed. These look very favourable as much of the required technology is already available on the tractor/sprayer and harvester for other purposes.

In the longer term the traceability concepts may well provide the technological support for automated carbon trading between businesses and have international significance with the development of issues effecting global warming and energy scarcity. These issues are well documented in the Stern Report (http://www.hm-treasury.gov.uk/media/8AC/F7/Executive_Summary.pdf).

8. CONCLUSIONS

There have been a significant number of advances to improve labour and machine management which will reduce the cost of many field operations by increasing the productivity of both man and machine. Critically, reducing cultivation costs whilst maintaining yield is vital in today's agricultural climate and any operation to minimise compaction and to control traffic to predetermined lanes has to be advantageous. Weeding mechanisms that permit the removal of intra-row weeds are vital to the successful adoption of high quality vegetable crops at much reduced cost to both the conventional and organic farmer. Telematics are permitting the status of machine performance and operating condition to be monitored by the supplier such that the machine may be adjusted for optimal performance and early fault detection prevents machine breakdown. Work is developing to enable the automatic recording of agrochemicals as they are loaded into the crop sprayer to prevent the mis-loading of product, the incorrect dilution, and application rate and field location. The fact that this can be conducted automatically should improve the accuracy of the data and reduce the time devoted to record keeping.

9. REFERENCES

- Ansorge, D. and Godwin, R. J. 2006. High Axle Load – Track – Tire Comparison. In: *Advances in GeoEcology, Soil Management for Sustainability*, edited by Horn. R. et al, CATENA VERLAG GMBH, Germany.
- Chamen, W. C. T. 2006 Controlled traffic on a field scale in the UK. In: *Proceedings of the 17th Triennial Conference of the International Soil Tillage Research Organisation*, eds. Horn R et al, Kiel, Germany, 845-852.
- Dedousis, A. P., Godwin, R. J., O'Dogherty, M. J., Tillett, N. D. & Brighton, J. L. 2006a. Effect of implement geometry and inclination angle on soil failure and forces acting on a shallow rotating disc for inter and intra-row hoeing. In: *Advances in GeoEcology, Soil Management for Sustainability*, edited by Horn. R. et al, CATENA VERLAG GMBH, Germany, 38, 15-20.
- Dedousis, A.P., O'Dogherty, M. J., Godwin, R J, Tillett, N. D., & Brighton, J. L. 2006b. A novel approach to precision mechanical weed control with a rotating disc for inter and intra-row weed hoeing. In: *Proceedings of the 17th Triennial Conference of the International Soil Tillage Research Organisation*, eds. Horn R et al Kiel, Germany, 123-129.
- Gasparin, C. P., Peets, S., Blackburn, D. W. K. AND Godwin, R. J. 2007. Stakeholder Requirements for Traceability Systems. In: *Proceedings of the 6th European Conference in Precision Agriculture*, ed. J V Stafford, Wageningen Academic Publishers, The Netherlands.

- Godwin, R. J., and Spoor, G. 1977. Soil failure with narrow tines. *Journal of Agricultural Engineering Research*, 22(3), 213-228.
- Home, M. 2003. An investigation into the design of cultivation systems for inter- and intra-row weed control. Unpublished EngD, Cranfield University at Silsoe, Silsoe, Bedford, MK454DT, UK
- Maguire, S., Earl R., Smith, D. F., Cripsey P and Godwin R. J. 2003. Technology for variable rate precision drilling of onions. In: *Proceedings of the 4th European Conference on Precision Agriculture*, eds. J V Stafford & A Werner, Wageningen Academic Publishers, The Netherlands.
- O'Dogherty, M. J., Godwin, R. J., Dedousis, A. P., Brighton, J. L. and Tillett, N. D. 2007. A mathematical model of the kinematics of a rotating disc for inter and intra-row hoeing. *Biosystems Engineering*, 96 (2), 169-179.
- Peets, S., Gasparin, C. P., Blackburn, D. K.W. and Godwin, R. J. 2007. RFID tags for identifying and verifying agrochemicals in traceability systems. In: *Proceedings of the 6th European Conference in Precision Agriculture*, ed. J V Stafford, Wageningen Academic Publishers, The Netherlands.
- Pullen, D. W. M. and Cowell, P. A. 2006. The effect of implement geometry on the hoe path of a steered rear-mounted inter-row weeder. *Biosystems Engineering* 94 (3), 373-386.
- Tillett, N. D., Hague, T., Miles, S. J. 2002. Inter-row vision guidance for mechanical weed control in sugar beet. *Computers and Electronics in Agriculture* 33, 163-177
- Tillett, N. D. and Hague, T. 2006. Increasing work rate in vision guided precision banded operations. *Biosystems Engineering* 94 (4), 487-494.
- Tillett, N. D., Hague, T., Grundy, A. C. and Dedousis, A. P. 2007. Mechanical within-row weed control for transplanted crops using computer vision. *Biosystems Engineering* (submitted).
- Tullberg, J. N. and Murray, S. T. 1986. Controlled Traffic Cropping. *Proceedings of AgEng 1986 Conference*, Wageningen, The Netherlands.
- Tullberg, J, Yule, D F and McGarry, D (2003). 'On track' to sustainable farming systems in Australia. Keynote paper, 16th ISTRO Conference, Brisbane.
- Vermeulen, G. D., Mosquera Losada, J., Van Der Wel, C., Van Der Kloosteren, A. and Steenhuizen, J. W. 2007. Evaluation of controlled traffic farming on an organic farm in the Netherlands. In: *Proceedings of the 6th European Conference in Precision Agriculture*, ed. J V Stafford, Wageningen Academic Publishers, The Netherlands.
- Watts, A. J., Miller, P. C. H., Godwin, R. J. 2003. Automatically recording sprayer inputs to improve traceability and control. In: *Proceedings of the 2003 BCPC congress Crop Science & Technology*, Glasgow, BCPC Publications, UK, pp323-328.
- Watts, A. J. 2004. The monitoring and control of chemical inputs to arable farming systems. EngD thesis. Cranfield University at Silsoe, Silsoe, Bedford, MK454DT, UK
- Wheeler, P. N., and Godwin, R. J. 1996. Soil dynamics of single and multiple tines at speeds up to 20 km/h. *Journal of Agricultural Engineering Research*, 63, 243-250.