# GPS GUIDANCE OF MECHANIZED SITE PREPARATION IN FORESTRY PLANTATIONS: A PRECISION FORESTRY APPROACH

**S. C. Husband**

*Forestry Plantations Queensland*
*Queensland, Australia*

## ABSTRACT

This paper examines application of precision agriculture and GPS guidance technology to mechanized site preparation in forestry plantations. There has been no research published to date on applying GPS guidance technology and software to site preparation in forestry plantations, despite clear similarities between plantation forestry and broad-acre agriculture applications of GPS guidance. The research setting is the Fraser Coast region of South East Queensland, Australia, and the *Pinus* plantations in this region managed by Forestry Plantations Queensland (FPQ). A literature review is combined with data collected from interviews with forestry operational staff, researchers, precision agriculture consultants and spatial information specialists. Potential economic, environmental, human and management benefits in applying GPS guidance and associated systems to plantation site preparation are identified. The paper concludes that definitive cost/benefit analysis and technical evaluation of GPS automatic (and visual) guidance systems in plantation site preparation should be determined by field trial. GPS guidance of site preparation in forestry plantations can help meet key objectives of precision forestry in terms of sustainable forest management, commercial objectives, and increasing environmental and social constraints.

**Keywords:** Precision forestry, GPS guidance, plantation site preparation

## INTRODUCTION

This paper examines application of precision agriculture (PA) and GPS guidance technology to site preparation in forest plantations. The primary focus is GPS guidance of mechanized site preparation operations.

The research setting is the *Pinus* plantations managed by Forestry Plantations Queensland (FPQ) in the Fraser Coast region of South East Queensland, Australia. Intensive management - in terms of inputs, design and activity - characterizes these *Pinus* plantations (90,000 hectares or 347 square miles).

A literature review surveys current and past developments in PA and precision forestry. Data were also collected through semi-structured, informal interviews. These were conducted with PA consultants; forest managers, forest researchers, and forestry GIS staff; and FPQ machine operators. Australian Forestry Standard (AFS) forest certification criteria provided a benchmark for discussion of research implications for sustainable forest management (Australian Forestry Standard, 2009).

In its 1997 report on PA the US National Research Council observed that the high economic value of forest products justified extensive use of site-specific technologies (US National Research Council 1997). In addition to generating employment, income and forest products, plantations are increasingly recognized as significant sources of environmental services and carbon sequestration (FAO, 2007).

Despite clear similarities between plantation forestry and broad-acre agriculture applications of GPS guidance. There has been no research published to date on applying GPS guidance to site preparation in forestry plantations in Australia (M. Brown and M. Strandgard, Cooperative Research Centre for Forestry, pers. comms.), or in the USA and Canada (R. Reynolds, FP Innovations, pers. comm.) on GPS guidance in forestry site preparation.

## METHODOLOGY

This paper employs two complementary methods. Firstly, a literature review summarizes current state of research and theory in precision agriculture, precision forestry, GPS automatic guidance and forestry plantation site preparation. Secondly, and based in turn on the literature review, interviews were conducted with key informants. Interview data are collated and discussed in light of literature review findings.

An important methodological question is whether interviews are the best way to collect data and information. Interviews may be the only feasible method of data collection where complex information is required, especially if differing opinions and perspectives are involved (Pannell and Pannell, 1999). Interview norms, rules and roles are well understood and tacitly accepted (Fontana and Frey, 2005).

There is a range of different interview types (Fontana and Frey, 2000; Minichiello et al., 2008). Among these the semi-structured interview is a reliable and flexible data-gathering tool. The semi-structured interview consists of pre-arranged questions usually of set wording and order, as well as additional extempore or supplementary questions.

Fontana and Frey (2005, p.698) observe that interviews are ‘*not neutral tools of data gathering but rather active interactions between two (or more) people leading to negotiated, contextually-based results*’. For example, the organizational setting of Forestry Plantations Queensland affects what employees say, how policies and work practices are implemented, and how employees and managers respond to change.

Face-to-face interviews are expensive and time-consuming to conduct, transcribe and interpret. The interviewee may embellish responses, give answers that are socially or contextually desirable rather than honest, or omit relevant information (Fontana & Frey, 2000).

Minichiello et al. (2008) describe key informants as those with privileged knowledge and expertise. Key informant groups of interest to this project were identified as follows: 1. forestry machine operators; 2. forest managers and silvicultural scientists; and 3. forestry GIS/GPS practitioners and GPS guidance consultants.

Questionnaire design was shaped by preliminary informal discussions with people from each of the key informant groups. Two questions were common to all questionnaires. Questions were worded to be easy to understand, short and free of jargon as possible. A basic fact sheet on GPS guidance was given to all questionnaire interviewees with the interview questions. at least one day beforehand. Three interview questionnaires were developed for this paper, one for each key informant group. Each questionnaire consisted of four to six pre-arranged questions of fixed wording, with additional question points and space for extempore questions to be asked as the interview developed.

Seven face-to-face interviews were recorded from 8 April to 27 May 2009. In addition, two written responses to interview questionnaires were received. Outside the key informant groups, written email responses on specific technical issues were received from five respondents. One interview regarding technical issues was conducted by phone and two face-to-face interview regarding technical issues were conducted. In these cases notes were taken by hand.

Data analysis was based on themes identified in the literature review, and additional issues arising from the interviews themselves. Interviewee responses were structured by questionnaire design, the fact sheet and interviewer contributions/interventions. Selective transcription from the interviews followed key themes and issues.

## LITERATURE REVIEW

An extensive search found no papers specifically dealing with precision agriculture or GPS guidance applications to forestry site preparation. Databases and search engines included ScienceDirect, Springerlink, CSA Illumina, ProQuest, American Society of Agricultural and Biological Engineers, USDA Forest Service Southern Research Service publications database, and Google.

Fifty-seven references were examined. Of these, 19 (33%) were peer-reviewed journal articles, 21 non-peer reviewed (37%) (12 conference papers [21%] and 9 Internet-based references [16%]), 9 government reports (16%), 7 books and book articles (12%), and 1 thesis (2%).

Ramalingam et al. (2000, unpaged) define automatic guidance as a system which '*determines current position and orientation of the vehicle, compares it to a desired position, and makes appropriate steering control to direct the vehicle towards the desired posture*'.

Wilson (2000) reviews the history and development of automatic guidance of agricultural vehicles, as well as summarizing past research in the area. Other key articles on automatic guidance include Ramalingam et al. (2000); Zhang et al.

(2002); Han et al. (2004); Yahya et al. (2005); Tillett and Hague (2006); Jochinke et al. (2007); and Bochtis and Vougioukas (2008).

Automatic guidance steers an agricultural machine more accurately than a human operator. Auto-steer technology builds on positioning systems to guide vehicles in predetermined patterns. RTK (real time kinematic) GPS further increases position accuracy to 2 centimetres (0.787 inches) by using relatively close (within 50 kilometres [31 miles]) permanent or temporary base stations (Blackmore et al., 2002; Tillett and Hague, 2006).

There is no universally accepted definition of precision forestry (Taylor et al., 2002). These authors emphasize the unique circumstances of forestry vis-à-vis other PA applications. These differences include relatively long crop harvest cycles (4 years to more than 100 years), much stricter environmental and other legislative requirements and restrictions, different site preparation and tending requirements as part of long-term silvicultural systems, and landscape and catchment scales of management.

Both Dooley and Fridley (2001) and Taylor et al. (2002) believe precision forestry will deliver better economic and environmental outcomes for forestry.

Virtually all forestry research on GPS guidance has focused on harvest vehicles and machines (Lofgren, 2006; Veal et al., 2001). Taylor et al. (2002) assert that GPS guidance offers many possibilities for improved forest operations.

Forestry site preparation can be defined as '*one part of a silvicultural system that may be carried out prior to or after a (forest) reproduction method…(and) includes any treatment that modifies existing vegetation or physical site conditions to improve germination, survival and subsequent growth of seedlings*' (Forest Encyclopedia Network, 2009). Costantini et al. (1997) identify the period between harvest and re-establishment of tree cover as the time of highest risk to soil and water values.

Forestry site preparation tillage operations consume greater amounts of energy than similar agricultural tillage operations due to increased debris, rougher and often wetter ground conditions, and stump collisions (Veal et al., 2005).

Site preparation is a major source of soil erosion and sedimentation on forest lands (USDA Forest Service, 2006a). Increased mechanization of forestry operations endangers the most important basis of timber production – the soil (Matthies et al., 2006). Machine size and power, and implement size, have all increased markedly in recent decades (Wilson, 2000).

Vossbrink and Horn (2004) describe adverse impacts of modern forestry vehicles on forest soils. They note fragile forest soils with low bulk density, low precompression stresses and high permeability are vulnerable to compaction.

Forestry site preparation is an '*energy-intensive treatment with significant costs*' (USDA Forest Service, 2006a). Berg and Lindholm (2005) report significant energy use by forestry site preparation in Sweden in 1996-1997. In the USA, mechanized site preparation operations have been significantly reduced in recent years in order to cut overall costs (Veal et al., 2005).

Bochtis and Vougioukas (2008) use the American Society of Agricultural and Biological Engineers' concept of machine field efficiency $E_f$ – the '*ratio between productivity of a machine under field conditions and the theoretical maximum efficiency*'. They observe that $E_f$ varies with size and shape of field, pattern of operation, soil moisture and other site conditions. Automatic guidance offers significant savings in fuel, increased productivity and reduced labor costs (Gan-Mor and Clark, 2001; Blackmore et al., 2002; Yahya et al., 2005; Jochinke et al., 2008).

Forest management in Australia and many other countries is conducted within the constraints of legislation, community and public scrutiny, forest certification, global commercial objectives, and a general trend towards more sophisticated forestry practice. The basic challenge '*facing resource managers is matching the requirements of the management plan to the capabilities of the forest operation*' (USDA Forest Service, 2006b).

## RESULTS AND DISCUSSION

### Technical issues – GPS guidance systems, machines and equipment

GPS automatic guidance systems currently available in Australia cost around A$20000-25000. This figure includes portable RTK differential GPS (DGPS) base stations (A$7000-8000). GPS automatic guidance kits are machine-transferable and interface with machine-specific steering kits. Average cost of steering kits is A$10000. Retro-fitting GPS guidance steering kits to FPQ skidders would require hydraulic adaptations at a small extra cost. Equipment costs are falling over time – in 1997 the minimum cost of a GPS automatic guidance kit was A$50000 (Kubik, 1997).

GPS guidance system accuracy depends on equipment cost and sophistication; distance to base station; satellite access; and integrity of signal communication between machine and base station. Fixed permanent or portable base stations transmit positioning signals by radio up to 50 kilometres (31 miles) enabling up to 2 centimetres (0.787 inches) accuracy in pass-to-pass machine applications. Networked base stations offer advantages of security and flexibility but these have to be offset against subscription costs.

GPS guidance is suited to forestry operations by skidders and excavators. Skidders are a robust utility machine with a high level of flexibility, capable of rapid deployment across a number of activities including non-site preparation activities. These articulated, rubber-wheeled machines have been modified for forestry use and are viewed as long-term ownership items (10-15 years). They are valued at A$450,000.

The automatic guidance system can be over-ridden at any time by the machine operator. It steers the machine accurately along a pre-determined pass width and pattern and within set boundaries. Machine pass patterns can be set to parallel passes along a contour or in straight lines. Turning zones can be created with audible warning features which alert operators to approaching turning zones or no-go areas. Automatic guidance systems are compatible with ArcGIS software; in fact about 90% of Australian users use ArcGIS.

Recording treated areas is critical to forestry operations, mapping, planning and overall management. '*Ultimately what you really want is your net plantable area*' (interview). GPS guidance software records areas treated, treatment boundaries, implement and machine set-ups, and allows for printable work reports and maps (Farmscan, 2009).

## Forest management, silviculture and planning

### Site preparation and silviculture - the situation now

'*Currently we try to adapt a one-size-fits-all basically when we do our mechanized site prep.'* (interview). Site preparation at Fraser Coast is based on a combination of GIS-based design, field inspection and marking, and mechanized clearing and cultivation. Mapping derives from pre-GPS field survey and recent DGPS survey data.

Row widths have a large effect on stocking variation and are controlled by site preparation. With current tree row placements, estimated by eye in relation to the last completed row by the machine operator, row width varies significantly. Various techniques to gauge row spacing have been tried: '*in the past we had skidders with row guides and iron bars and bits of bloody rope and bolts dangling off them*' (interview).

'*We've had everything from say four metres to over six. I mean they're the extremes. We don't get those very much. It depends very much on the operator. I mean when operators are less skilled*" (interview).

'*Having more accurate row placement we can achieve better stocking regimes…the unskilled person, provided they have the skills in using the GPS system, his end product shouldn't really be much different* (from that of the skilled operator)' (interview).

All FPQ interviewees agreed that a major advantage of GPS automatic guidance would be accuracy of row placement. Accurate row spacing and straightness will mean cost savings and operational efficiencies in subsequent activities such as planting, post-plant herbicide spraying and weed management, plantation resource assessment, and possibly fire protection.

### Information flows and GPS guidance

'*I don't think we should limit our thinking to machines in this project. I think that's just the starting point*' (interview).

Accurate information is a key requirement for successful, profitable plantation silviculture. '*We do all this work out there but we really haven't got the tools to take a good stocktake of what we've got there, do we?'* (interview). '*Successful application of low-input silviculture involves a very good ability to be able to stratify a site and then to decide what's the bare minimum treatment that you can get away* (with) *putting on that site to get adequate plantation productivity at the end of the rotation…you must understand what your site is made of in terms of soil types and whether those soil types are going to fundamentally change what you do to get your plantation growing*' (interview).

GPS automatic guidance of site preparation may be used to collect and record information which can be used to direct future silvicultural operations, thinning, harvest and subsequent site preparation. Precision in establishment has important benefits in later silvicultural operations in the same area. GPS guidance mapping of hazards, especially wet areas, hardwood debris, and any other areas not accessible by machine, may improve future planning and operations.

‘*The obvious* (advantage) *is download direct to GIS and mapping…that’s a given*’ (interview). ‘*The collection of digital information about site changes, whether they’re soil types, wetness, debris levels, and the translation of those into treatment maps…has the potential to revolutionize the way that we think about and operate our sites*’ (interview).

‘*I think the recording of that information and transferring it between activities…I’d be surprised if there weren’t planning efficiencies in that which…should lead to operational efficiencies*’; ‘*…borrowing from PA and taking it here is the logical step. We’ve just got to decide what are the things on the ground that’ll make a difference in terms of changing our treatment*’ (interview).

**Measuring expenditure and performance in real-time**

‘*We may well find that the performance information side of it, of work done and getting that in real time may be one of the major benefits that we see of this*’ (interview).

GPS guidance technology may provide accurate, real-time data for monitoring work programs, work expenditure in labor costs and machine hours, machine productivity and usage rates, and machine maintenance scheduling. ‘*What that means is that we have real-time indicators of performance instead of lag-time indicators*’ (interview).

‘*Particularly if we line that up with a few key performance indicators in terms of operational targets…lining that up with feedback mechanisms from the machine and area covered, the operator would be able to get a real-time view of how they’re actually performing against that performance target and be able to adjust their behavior to completing that site or be able to inform their supervisor of any difficulties in achieving that target for that site*’ (interview).

‘*There’s no reason that the day’s...area can’t be loaded up against the financial system in terms of area done and lined up against hours worked*’ (interview). Performance indicators could be built into the guidance software and display, along with machine indicators such a speed, gearing, rpms, hydraulic pressure etc. ‘*These things I think in terms of performance, of how machines are performing and what sort of return on investment we’re getting on these machines, is critical*’ (interview).

**Human issues – training, working conditions, improved productivity and human resource relationships**

FPQ operators should need ‘*very little training…they should pick it up fairly quickly…I think just a bit of a crash course…I think they’d be fairly basic…to work*’ (interview). ‘*If their machines are fairly accurate and they produce a good result then obviously their* (the operators’) *confidence is going to increase*’ (interview).

‘*Plant operators – good plant operators – have more skills in being able to understand dials and read-outs than you’d probably first assume and this* (GPS guidance display) *is just another screen they’re going to refer to, particularly if we’re going to start integrating displays in the cab such that the operator is looking at one screen instead of a whole multiplicity of dials*’ (interview).

Field supervisors, managers and GIS staff will require training as well. '*Site designers would also need to become familiar with data downloads and develop protocols (with plant operators) for dealing with the various exclusion zones and setbacks to be considered as part of site design*' (interview).

GPS automatic guidance may improve working conditions for operators. Terrain conditions for forestry site preparation are very different from broad-acre agricultural operations. Hazards include hardwood and pine stumps, harvest debris, remnant vegetation, wet areas, steep slopes, rocky areas, and nearby work and vehicle activity.

'*In our terrain there's a constant need to adjust gearing, throttle, placement of the machine through debris and over stumps that needs operator attention although I think that introduces fatigue of another sort, fatigue through tiredness, not fatigue through boredom, but I think yes it would help you know if the operator doesn't have to concentrate on his row spacing, he can concentrate because the machine is keeping him on the row or lane that's on the tracking system*' (interview).

'*I think it* (will) *maybe for a lot of them give them more job satisfaction*' (interview).

At present machine operators have little input into design implementation and little operational autonomy. GPS automatic guidance in conjunction with real-time performance monitoring and recording software may improve work practices and operator autonomy and pay. '*What that basically means is that supervision for area done becomes less of a responsibility for the field supervisor who can concentrate on planning and getting efficiencies out of planning and directly relates to the operator…Being paid more may rest upon the ability to self-supervise through these systems*' (interview).

## Environmental issues – minimizing impacts, maximizing benefits

Mapped boundaries built into the digital design will help to limit machine activity to more favorable areas within predetermined working boundaries and patterns. There would be '*less scope for any sustained environmental harm to the site if the tracking system can be tailored to the contours of the land*' (interview).

GPS guidance treatment maps will record precisely area and nature of treatments. These can then be used to form a chain of evidence of sustainable forest management conducted according to certification and legislation requirements.

'*I think from a sustainability perspective in terms of machine passes over the ground, compaction issues, yeah some benefits you can see there but I think it's more from the benefit of being able to record what the treatment was on the ground accurately and having a verifiable chain of evidence…of what's been done which is a key thing to showing systematic management under AFS* (Australian Forestry Standard) *criteria*' (interview).

## Economic costs and benefits

'*I suppose the major disadvantage that springs to mind is the need to convince the organization that they should invest the money in the technology*' (interview).

Costs associated with introducing GPS guidance to forestry site preparation fall into four categories: 1. purchase and installation, 2. training, 3. work practice/systems adaptations, and 4. maintenance, upgrades and base station network subscription.

'*Disadvantages? Yeah, cost, I think initially, but when you look at the cost of the whole machine and this as an extra to the machine it's not that great… this is not big money*' (interview).

In 1997 the cost of GPS guidance equipment in the USA was calculated as US$0.75-1.45 per acre based on equipment life of 3 years, 6% interest rate, 3% repair cost and 1000 acres worked (US National Research Council 1997). '*Like most technology they will probably get cheaper, making them a more attractive proposition*' (interview).

'*If we said we've got a machine which is costing us in the order with operator of A$120-130 an hour out there, okay now if we add the cost of the software and hardware to run this and let's just say it's A$25000 on top of the cost of a new machine, okay that is over the life of the machine amortised. That's only going to add a couple of dollars per hour to running that machine – if that, and that's where it counts, that's what you're looking at…it's the amortised cost over the life of the machine and the work it does is where this should be considered, not just as a bolt-on extra…and that's your key performance measure in terms of this: "all that extra cost per hour, do I redeem that in extra productivity per hour?*" ' (interview).

Costs will also be recouped by efficiencies associated with reduced planning and field inputs, improved mapping, work program and performance monitoring, increased productivity, fuel savings, downstream savings in later phases of plantation silviculture, and better recording of work done.

'*I can picture this working quite well…these are good developments from a GIS perspective…now it's about cost/benefit*' (interview). '*The less times you touch a site the cheaper it is*' (interview). '*It comes down to a question of how many times you visit that place and that comes down to cost*' (interview).

**GPS guidance – problems and difficulties**

Interviewees described a number of disadvantages of GPS guidance in plantation site preparation.

'*We're talking about a 30 year rotation so you'd expect things will change*' (interview).

'*Related to the cost is the willingness of plant owners to invest in this technology and associated modifications to plant items, especially (as in contractors) if there is no minimum work guarantee linked to the investment to enable them to recoup their costs. Site preparation techniques can change rapidly making some investments rapidly redundant*' (interview).

'*Provision of after-sales service I suppose…(it) takes a while to schedule someone to come out and fix* (problems)*…and given the establishment program we've got and current considerations in relation to the maintenance of machinery and the problems they produce from time to time, it may add significantly to the down time for machines*' (interview).

Security may be an issue with machine break-ins: GPS units, receivers and base stations may be an added risk, although short-term removal may be an option. Receivers mounted on the cab may be vulnerable to damage from vegetation and flying debris, especially when skidders are used for fire protection activities such as maintaining breaks, and building breaks during wildfires.

There were some concerns that operators may become lazy and inattentive when using GPS automatic guidance. (These are also problems without GPS guidance.)

'*I wouldn't like to see it being used as an excuse for poor work standards – "oh this bloody thing told me to go there so I just kept going"* ' (interview).

'*I know if you're getting sleepy you tend to veer off course a bit whereas this* (with GPS guidance) *you stay on line so you might be tempted to sort of push on and maybe drift off but I guess that's up to the operator to manage that*' (interview).

**Introducing change – champions and resisters**

Introducing change to an organization is itself a challenge, independent of the nature of the change. Several interviewees either saw this as a problem or counseled attention to managing change sensitively and positively. '*Many a good technological idea has fallen down because of cultural change*' (interview). '*Don't underestimate the resistance to change…that is, by managers and field supervisors, not so much plant operators*' (interview).

'*The first thing the shutters'll go up…there's a culture shock…in forestry you know that…We'd have to manage and we'd probably have to do some training. Some of our guys would prefer to run a mile rather than use this technology*' (interview).

'*I think there'd be a little bit of operator resistance...there may be a bit of a perception by some of the operators that the ability to think has been taken away from them with these systems in their machine. For example if something isn't picked up on the ground and they're going to be totally guided by the system, it takes away a little bit of that being able to change horses in midstream*' (interview).

'*Often when you're introducing change to an organization the notion of that change being unchosen causes resistance…operators and people at the coal face tend to, when they see a technological change which is to their advantage, tend to grasp it and be enthusiastic about it…middle level managers often tend to be somewhat conservative about change unless of course they've thought about it because it upsets the existing paradigm of which they have control*' (interview).

There is a need to '*stand back and have a clear vision of what you're trying to achieve for the organization …and this project is clearly about using technology to enhance efficiencies. Once these efficiencies have been demonstrated it's then about applying these efficiencies across the work program to get financial benefit…it's then about how you manage your HR (human resource) processes to achieve that and that's through engagement of staff to understand and accept change*' (interview).

If GPS guidance technology is to be introduced to FPQ site preparation, this project and associated interviews may be a first step in the process of engaging staff, and promoting understanding and acceptance of change.

## CONCLUSION

Site preparation is a key phase of plantation management. It is highly mechanized and involves significant inputs. Environmental impacts of mechanized site preparation are potentially high.

Economic, environmental and social pressures have encouraged adoption of precision agriculture technologies and techniques. These involve, among other aspects, fine-scale site-specific management, and applications of new spatial and information technologies to agricultural systems.

Precision forestry encompasses actual and potential applications of precision agriculture to forestry. Differences between forestry and other arenas of PA application include relatively long crop harvest cycles, much stricter environmental and other legislative requirements, different site preparation and tending requirements, and landscape and catchment scales in management.

There has been no published work to date on applying GPS guidance to mechanized forestry site preparation. This is despite significant parallels between forestry site preparation and broad-acre agricultural applications where GPS guidance is a widely accepted technology.

The literature review found that GPS guidance of forestry site preparation may have considerable economic, environmental, management and human benefits. Data collected from respondents in the course of the project interviews extended this list of benefits. Many benefits relate to more than one category: for instance, improved accuracy of site preparation treatment through using GPS automatic guidance may have benefits extending across all four benefit categories.

Some key benefits identified include increased productivity; real-time monitoring of operational performance; fuel savings; accurate identification and observation of environmentally sensitive areas, including watercourses and special management areas; immediate download of digital data relating to work performed, work rates, untreated and treated areas, and field hazards; more precise field implementation of plantation design; improved information capture, storage and analysis; and improved working conditions for machine operators.

This paper identified potential problems with application of GPS automatic guidance to forestry site preparation. These include terrain conditions on forestry sites, especially after clearfall harvest, different from broad-acre agricultural work sites; contractor reluctance to invest in automatic guidance technology; training and implementation costs; security issues; and organizational resistance to change.

GPS guidance of forestry site preparation, combined with applications associated with information-rich, technologically sophisticated precision forestry, has the potential to improve commercial, management and environmental outcomes in plantation forestry.

Definitive cost/benefit analysis and technical evaluation of GPS guidance systems in plantation site preparation can best be achieved by a field trial. A trial will test system capabilities on a forestry work site across a range of site preparation activities. A field trial may also gauge training needs, staff acceptance, data requirements such as mapping, guidance system refinements, and new work practice and design requirements.

## ACKNOWLEDGMENTS

I acknowledge with gratitude the following people who supported and contributed to this paper: particularly Dr Madan Gupta, University of Queensland; Dr Jeff Tullberg, University of Queensland and CTF Solutions; Michael Robinson and Col Reugebrink, Forestry Plantations Queensland; Tim Neale, CTF Solutions; Matt Higgins, Queensland Department of Environment and Resource Management; and Martin Strandgard, Cooperative Research Centre for Forestry and University of Melbourne.

## REFERENCES

Australian Forestry Standard. 2009. Australian Forestry Standard. From http://www.forestrystandard.org.au/14AFCS.asp

Berg, S., & Lindholm, E.-L. 2005. Energy use and environmental impacts of forest operations in Sweden. J. of Cleaner Production, 13(1): 33-42.

Blackmore, S., Have, H., and Fountas, S. 2002. Specification of Behavioural Requirements for an Autonomous Tractor. Paper presented at the Automation Technology for Off-Road Equipment Conference, July 26-27, 2002, Chicago, Illinois, USA. Publication Date July 26, 2002. ASAE Publication Number 701P0502, ed. Qin Zhang.

Bongiovanni, R., and Lowenberg-Deboer, J. 2004. Precision agriculture and sustainability. Precision Agriculture. 5: 359-387.

Bochtis, D. D., and Vougioukas, S. G. 2008. Minimizing the non-working distance travelled by machines operating in a headland field pattern. Biosystems Eng. 101(1): 1-12.

Costantini, A., Dunn, G.M., and Grimmett, J.L. 1997. Towards sustainable management of forest plantations in south-east Queensland. II: Protecting soil and water values during second-rotation *Pinus* plantation management. Australian Forestry. 60(4): 226-232.

Dooley, J. H., and Fridley, J.L. 2001. Near-Surface Sensing and Mapping for Site-Specific Operational Decisions in Precision Forestry. Paper presented at the 2001 ASAE Annual International Meeting., Sacramento, California, USA. Retrieved 30.1.2009 from http://asae.frymulti.com.ezproxy.library.uq.edu.au

Farmscan. 2009. AgGuide Rowguide Product Sheet. Retrieved 7 June 2009 from http://www.farmscan.net.au/default.aspx?MenuID=64

Fontana, A., and Frey, J.H. 2000. The Interview: From Structured Questions to Negotiated Text. In Denzin N.K., and Lincoln, Y.S. (Eds.). Handbook of Qualitative Research. 2nd ed. Sage Publications, Thousand Oaks.

Fontana, A., and Frey, J.H. 2005. The Interview: From Neutral Stance to Political Involvement. In Denzin N.K., and Lincoln, Y.S. (Eds.), The Sage Handbook of Qualitative Research. 3rd ed. Sage Publications, Thousand Oaks.

Food and Agriculture Organization (FAO). 2007. State of the World's Forests 2007. Retrieved 30.8.2008 from http://www.fao.org/forestry/sofo/en/

Forest Encyclopedia Network. 2009. Resource Management: Silviculture: Site Preparation. Retrieved 29.1.2009 from http://www.forestencyclopedia.net/p/p1695

Gan-Mor, S., and Clark, R.L. 2001. DGPS-based automatic guidance - implementation and economic analysis. Paper presented at the 2001 ASAE Annual International Meeting. Retrieved 30.1.2009, from http://asae.frymulti.com.ezproxy.library.uq.edu.au

Han, S., Zhang, Q., Noh, H., and Shin, B. 2004. A dynamic performance evaluation method for DGPS receivers under linear parallel-tracking applications. Trans. ASAE 47(1): 321-329.

Jochinke, D. C., Noonan, B. J., Wachsmann, N. G., and Norton, R. M. 2007. The adoption of precision agriculture in an Australian broadacre cropping system: challenges and opportunities. Field Crops Res. 104(1-3): 68-76.

Kubik, J. 1997. Automated Tractor Control Using GPS. University of Queensland Bachelor of Engineering (Honours) Thesis, Brisbane.

Lofgren, B. 2006. Automation of forestry machines - an important piece in precision forestry. Paper presented at the 2006 IUFRO Precision Forestry Symposium. Retrieved 29.1.2009, from http://academic.sun.ac.za/forestry/precision/papers/14.pdf.

Matthies, D., Kremer, J., Ziesak, M., Wolf, B., and Ganther, C. 2006. Precision forestry and site sustainability. Paper presented at the 2006 IUFRO Precision Forestry Symposium. Retrieved 29.1.2009, from http://academic.sun.ac.za/forestry/precision/iufro2006.html.

Minichiello, V., Aroni, R., and Hays, T. 2008. In-depth Interviewing: Principles, Techniques, Analysis. 3rd ed. Pearson Education Australia, Sydney.

Pannell, P. B. W., and Pannell, D.J. 1999. Introduction to Social Surveying: Pitfalls, Potential Problems and Preferred Practices. SEA Working Paper 99/04. Retrieved 29.1.2009 from http://cyllene.uwa.edu.au/~dpannell/seameth3.htm

Ramalingam, N., Stombaugh, T.S., and Mirgeaux, J. 2000. DGPS-Based Automatic Vehicle Guidance. Paper presented at the ASAE Annual International Meeting. Accessed December 2008 from http://www.bae.uky.edu/precag/PrecisionAg/Reports/guidance/guidance.htm

Taylor, S. E., Veal, M.W., Grift, T.E., McDonald, T.P., and Corley, F.W. 2002. Precision Forestry: Operational Tactics for Today and Tomorrow. [Electronic Version]. Retrieved 27.1.2009 from http://eng.auburn.edu//files/file169.pdf..

Tillett, N. D., and Hague, T. 2006. Increasing Work Rate in Vision Guided Precision Banded Operations. Biosyst. Eng. 94(4): 487-494

US National Research Council. 1997. Precision Agriculture in the 21st Century: Geospatial and Information Technologies in Crop Management. Retrieved 23 March 2009, from http://encore.library.uq.edu.au/iii/encore/search/C%7CSPrecision+agriculture+in+the+21st+Century%7COrightresult%7CU1?lang=eng&suite=def.

USDA Forest Service. 2006a. New and Innovative Methods and Technologies to Reduce the Impacts of Forest Operations. Retrieved 29.1.2009, from http://www.srs.fs.usda.gov/forestops/problem2.htm

USDA Forest Service. 2006b. Forest Operations Research. Retrieved 29.1.2009 from http://www.srs.fs.usda.gov/forestops/home.htm

Veal, M. W., Taylor, S.E., McDonald, T.P., McLemore, D.K., & Dunn, M.R. 2001. Accuracy of tracking forest machines with GPS. Trans. American Soc. Agric. Eng. 44(6): 1903-1911.

Veal, M. W., Taylor, S.E., Rummer, R.B., & Raper, R.R. 2005. Plow power requirements for forestry site preparation. Int. J. Forest Eng. 16(2): 129-136.

Vossbrink, J., & Horn, R. 2004. Modern forestry vehicles and their impact on soil physical properties. Eur. J. Forest Res. 123(4): 259-267.

Wilson, J. N. 2000. Editorial: Guidance of agricultural vehicles - a historical perspective. Comput. Electron. Agric. 25(1-2): 1-2.

Yahya, A., Zohadie, M., Kheiralla, A.F., Gew, S.K., Wee, B.S., & Ng, E.B. 2005. Precision system for mapping terrain trafficability, tractor-implement performance and tillage quality. Paper presented at the Proceedings of the Seventh International Conference on Precision Agriculture, July 25-28, 2004, Minneapolis, Minnesota, USA. Retrieved 29.3.2009 from http://www.usyd.edu.au/agric/acpa/articles.htm

Zhang, N. Q., Wang, M. H., & Wang, N. 2002. Precision agriculture – a worldwide overview. Comput. Electron. Agric. 36(2-3): 113-132.