

THE UNIVERSITY OF ADELAIDE

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“I can’t be green if I’m in the red”:  
Combining precision agriculture and remote sensing  
technologies for sub field and regional decision  
making

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Gregory Maxwell Lyle

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## **Appendix 1: Drivers and determinants of natural resource management adoption at the farm scale**

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<sup>1</sup>Lyle.G and B. Ostendorf<sup>1</sup>

**Keywords:** *Natural Resource Management; Farming; Decision Making.*

### ***Extended abstract***

The environmental degradation caused by agricultural practices in the Australian grains industry has caused a change in the way we think about the industry and its effect on the environment. Emphasis is now placed on achieving economic social and environmental outcomes, the triple bottom line. Government, regional and industry organisations are using various instruments of influence to exert pressure on grain growers to implement better on-farm natural resource management (NRM) practices. Past strategies aimed at influencing the grower by appealing to their land stewardship and altruisms have proved worthwhile, as evidenced by increasing grower understanding of NRM problems. However, there has been a failure to deliver significant on-ground changes. Research into the adoption of NRM has suggested that the major factors that influence uptake are farm income, education and future farm planning. Other factors, such as individual farmer and social characteristics, have been identified as less important.

A study by Gallopín (2002, pp. 361-392 in: Gunderson, L.H. and Holling, C.S. (eds), *Panarchy: Understanding Transformations in Human and Natural Systems*, Island Press, Washington) suggests that decision making processes for sustainable development are hampered by a (1) lack of political willingness, (2) a deficiency in understanding of environmental problems and their consequences and (3) the insufficient adaptive capacity (both financial and social) to act on the changes needed in the realm of physical possibility. This characterisation of the decision domain provides a useful model of the NRM adoption

situation in Australia. The authors suggest that the pressure groups identified above will drive the willingness and understanding of future growers perceptions; whereas capacity is solely left to the individual grower. Here any decision to undertake NRM is based on uncertainty of the consequences of this adoption. There is much scope for research into the physical capacity of the farm to undertake NRM i.e. what are the benefits and costs of adopting NRM strategies. The application of precision agriculture technology into this area can reduce the uncertainty in the decision making process by being able to quantify both the short-term effect on grower's income and long-term effect on environmental degradation.

The aim of this paper is to highlight the drivers and determinants of NRM adoption at the farm scale. This paper also identifies additional information that will be needed if any real on-ground changes are to occur on ground. The "farms capacity to change" should be examined ahead of the grower's capacity to adopt if the grower's uncertainties about NRM practices are to be diminished. This paper identifies precision agriculture and more specifically yield mapping, as a technology for reducing the uncertainty in the decision making process because data is collected at a scale in which these NRM decisions are made. Precision agriculture can estimate the opportunity costs associated with NRM adoption and further help in the understanding of the degree to which a farm can adopt NRM practices. Growers cannot be green if they are in the red.

### ***Introduction***

Australia's landscapes are not well suited to agricultural production and the environmental degradation caused by agricultural practices in Australia has been well documented. Degradation of the landscape can take many forms but the problems receiving greatest attention are salinity and water quality. With this increased insight into degradation problems and their negative effects on agricultural regions, there has been a shift within society to a more environmentally friendly paradigm. Government, regional and industry organisations are using various instruments of influence to exert pressure on grain growers to implement better on-farm natural resource management (NRM) practices. These groups highlight the need for growers to adhere to a triple bottom line approach, i.e. one that has a

balance of economic, social and environmental factors in order to sustain a profitable and resilient industry and rural economy.

For growers this may mean a choice of how they continue to farm. Growers could continue farming the land until the degree of degradation causes production to become unviable, a less environmentally damaging approach is the adoption of NRM practices. Practices such as the reassignment of cropping areas to create buffer zones of perennial vegetation could be implemented to minimize run off of salts and to combat rising water tables. For the grower who wants to attain an increase in environmental outcomes, the decision to apply this practice will be clouded by local factors such as the spatial variability of yield and the potential environmental benefits of NRM. This decision is further exacerbated by external factors such as climate variability and the volatility of the international commodity markets. Undertaking decision making in regards to the adoption of NRM practices will therefore be unpalatable to the landholder because of uncertainty about the impacts on their own triple bottom line.

This paper presents a brief account of the different pressure groups that will drive growers to undertake NRM within the Australian grains industry. The paper also highlights the current research into the determinants of NRM adoption and the additional benefit of precision agriculture technology in the decision making process.

### ***Drivers for NRM adoption***

This section briefly discusses the different NRM pressure groups and the situations which have arisen to create them. We believe that these groups will apply various instruments of influence to exert pressure on grain growers in Australia to implement better on-farm NRM.

#### *Government and regional catchment management authorities*

The Australian federal government, in agreement with States and Territories, have identified the need to develop regional investment strategies for the integrated delivery of NRM priority issues. The assessment for prioritising objectives was based on the National Land and Water Resource Audit that identified areas significantly affected by environmental degradation and the potential for cost effective preventative action. A total

of 56 regions were identified with each region creating its own targets and priorities in the form of a regional environmental action plan. This redistribution of decision making from state and federal policy makers to the regions is aimed at empowering the community by identifying local community issues. In order to develop targets, regional catchment bodies consult with all members of their community to develop a single vision for the region. The plans identify the shaping forces and threats to the NRM asset base as well as priorities, goals and opportunities for the region. With this as a basis, the CMA also identifies the region's investment strategies and framework as well as the monitoring, reporting and evaluation frameworks. The plans must be consistent with state and federal policies and strategies and once accredited are the basis for the distribution of regional investment from both the Natural Heritage Trust and the National Action Plan for Salinity and Water Quality.

In its regional NRM strategy for the Northern Agricultural region of Western Australia, the Northern Agricultural Catchments Council (NACC 2005) highlighted the broadness of the approach taken. NRM problems are complex and occur on various spatial and temporal scales. They are also likely to involve difficult trade-offs between alternative land uses and different community aspirations and values – at local, regional, state and national level.

### *The grains industry*

In 2004 the Grains Research and Development Commission (GRDC) developed its single vision framework for the Australian grains industry (GRDC 2004). The strategy highlighted key themes which emerged from grower interviews and a national grains industry conference namely that the future focus of the grains industry should be on a commitment to the triple bottom line of economic, environmental and social sustainability. The GRDC envisions that this approach embraces good farming practice as well as good environmental stewardship as the key to regional and industry prosperity. One major outcome of this approach is sustaining the industry's image of clean and green production ("the Green Continent" global branding GRDC 2004) in order for product differentiation in the global market. The document highlights a pathway from 2005 to 2025 where current production systems will use water more efficiently and the farming systems will be

redesigned in terms of restoration of land and natural vegetation capabilities. By 2020, GRDC expects that the industry will be seen to have a shared responsibility as a partner for NRM and regional community development.

### *Farming federation groups*

These triple bottom line objectives are further supported by the National Farmers Federation and their comparative state-based affiliates. In 2004, the South Australian Farmer Federation (SAFF) reported that a triple bottom line approach was needed out of necessity to stabilise declining rural populations. In its report, SAFF addressed the emerging triple bottom line objectives that are essential ingredients in modern day thinking about life in Australia. Their initiative builds on the identification of increased opportunities for providing environmental and community services in rural areas that the whole South Australian community can value and reward (SAFF 2004).

### *Regional farming system groups*

Ridley (2005) identifies the progress of larger high profile farming system groups (such as the Liebe Group in Western Australia) towards sustainable farming in Australia. The creation of these groups has been in response to regional issues and provides growers with an avenue to discuss local issues and act on options and opportunities which work locally in their region. Actions are firstly undertaken at the plot scale and if applicable are expanded to field or farm scale. Research from these groups focuses mainly on profitability and economic viability. Focus on environmental issues has been in response to the urgency and visibility of a problem or to a particular environmental 'champion' who raises awareness amongst the group (Ridley 2005). A major obstacle for research into environmental issues by these farming groups has been the lack of funding from research and development agencies which growers' identify with rather than the group's appreciation for environmental outcomes. The establishment of these groups has led to a common vision, ownership of environmental problems and they should be now more ready to tackle environmentally sustainable issues in a more meaningful way (Ridley 2005).

Wilkinson and Barr (1993) highlight the effects of peer pressure within communities dealing with complex environmental problems. They suggest that voluntary solutions were

more palatable than compulsory solutions. But compulsory solutions could work where the community engagement and leadership was strong, and the problem was seen as urgent leading to local community pressure.

### ***Actions by the grower***

With this increased focus on NRM to improve environmental outcomes the problem exists that the objectives of the grower are not those of the greater community. This problem is further compounded by environmental problems emanating at the landscape scale while actions by the grower are at the field and farm scale. These problems have meant that adoption of NRM in Australia has been limited. In order to understand the adoption of NRM at the grower level, research has focused on the economic, sociological and psychological attributes of landholders. Table 1 summaries the research into the determinants and factors that effect uptake of NRM and the adoption of specific NRM practices by the grower. These determinants can be classed into four main areas: 1) economic; 2) individual grower and social characteristics; 3) institutional issues, and; 4) adoption of a particular NRM practice. The literature suggests that understanding these factors and capacity for individual landholder to make NRM decisions will ensure more realistic and more effective catchment and regional plans. Unfortunately, studies using survey research into these grower attributes provided very few statistically significant explanatory variables (Cary et al. 2002, Herr et al. 2003 and Nelson et al. 2004). The majority of farmers adopting sustainable farming practices were members of Landcare or production groups. Economic factors including farm size, off farm income and level of farm equity also influenced the likelihood of adoption of NRM practices (Nelson 2004).

**Table 1 Determinants of NRM adoption in Australia. Taken from Cary et al. (2002), Herr et al. (2003), Nelson (2004), Nelson et al. (2004) and Ridley (2005).**

Economic	Level of farm income, business characteristics, farm size, equity, income needs, property management planning, off farm income, labour available, type and access to consultant
Individual grower and social characteristics	Values, goals, culture, peer group, cultural expectations of farming, motivation, adaptation, attitudes to NRM and NRM organisations, altruism, risk perception, education, skills, age, family, succession, participation in groups, demographics and socio-political structure in the community or catchment where the grower lives, ability to uptake specialist, strategic or organisational knowledge, local knowledge within catchment
Institution	Regulatory environment, government agency support structures, incentive schemes and taxation arrangements, adoption of Environmental Management Systems
Adoption of a particular NRM practice	Cost, relative advantage, complexity, risk characteristics, compatibility, trialability, observability, local information and effectiveness, neighbourhood uptake

Of greatest significance were the studies undertaken by Cary et al. (2002) and Herr et al. (2003) which found a negative link between equity (the degree to which a farm is debt-free) and adoption of NRM. Two plausible solutions have been offered for this negative correlation. Cary et al. (2002) suggested that managers with high equity ratios could be more risk adverse and thus less inclined to adopt what they might see as risky resource management technologies. Herr et al. (2003) offers an alternative insight with the quantification of the equity measurement. Equity can be seen as an absolute term and therefore growers with low value properties could have a low value of equity while growers with a high value property may have less equity. These results and views are contrary to the suggested theories that higher equity indicates better financial capacity to undertake NRM changes and therefore provide higher adoption rates.

Figure 1 provides further abstraction of Table 1 and was adapted from a study into the decision making process in sustainable development (Gallopín 2002). The study



highlighted three major obstacles and their interactions (Table 2), willingness (W), understanding (U) and capacity (C). The author suggests that the factors limiting sustainable development are a lack of political willingness, a deficiency in the understanding of environmental problems and their consequences and the insufficient adaptive capacity (both financial and social) to act on the changes needed. Figure 1 also shows the interaction between physical feasibility and the decision process by including the variable physical possible (P). By definition the capacity to do what is physically impossible cannot exist. The terms understanding and willingness allow for the acceptance of what is and is not physically possible, although situations exist where peoples' understanding leads to a willingness to undertake actions that are not physically possible (actions that breach physical and societal constraints).

NOTE:

This figure is included on page 248 of the print copy of the thesis held in the University of Adelaide Library.

**Figure 1 Intersections between physically feasible and decision processes (Gallopín 2002) where W = Willingness, U = Understanding, C =Capacity and P = Physically Possible.**

**Table 2 Actions taken from NRM adoption (Gallopín 2002)**

NOTE:  
This table is included on page 249  
of the print copy of the thesis held in  
the University of Adelaide Library.

The decision domain highlighted by Gallopín (2002) can help understand the situation of NRM adoption by landholders in Australia. Both economic and social capacities have been found to increase the likelihood of adoption. Although studies by Cary et al. (2002) and Herr et al. (2003) indicate that adoption of NRM may not be purely based on the financial situation of the farm business. In terms of understanding, the concept and introduction of the Landcare organisation has provided 10 years of information exchange into the understanding and identification of NRM degradation and strategies. A survey of broad acre and dairy farmers by Nelson (2004) reported that more than half of growers surveyed reported signs of degradation while 23 percent reported a significant degradation problem. It was further reported that only 7 percent of farmers faced with significant degradation felt that they were unable to effectively manage the problem mostly because effective management options were either unavailable or beyond their resources. This increase in understanding of the environmental degradation and strategies for amelioration was highlighted by Nelson (2004) stating that very few farmers indicated a need for further skills or information to help them address degradation issues. In terms of willingness, focus has been on incentives through market based instruments rather than regulatory policy to influence NRM by institutional organisations. Incentives such as tax write offs (Dodds 2003) and bush tenders (Stoneham et al. 2003) have been developed in order for growers to change farm management practices. Willingness to adopt has been limited due to uncertainty of the longer term benefits of NRM alternatives. The focus for government NRM programs in the future is to create new technologies for addressing recognised degradation issues, and enhancing economic incentives for their adoption.

Table 2 identifies the interactions between all 3 areas of NRM adoption. The pressure groups we have highlighted in section 2 can be seen to focus their influence on the

willingness and understanding obstacles and the conceptual intersection between the two. What limits appropriate adoption of NRM is that capacity is based on each individual grower's position. If growers believe that they have the capacity, are willing and have the understanding of how to adopt NRM, adoption may still not be beneficial to the grower. The decision for adoption still will be based in an environment of uncertainty of the resulting consequences.

What is needed is information on the physical and production characteristics at the sub-field, field and farm scale as well as how these scales interact at the greater landscape scale. Information at these scales will provide an understanding of the farm's ability to provide environmental benefits as well as the financial implications to the grower. Unfortunately, local information, impacts and knowledge needed for tackling land and water degradation is often deficient (Cary et al. 2002). The capacity to make decisions at this scale is further pointed out by catchment groups when dealing with the issue of salinity. Advice at a field scale is essential for landholders to make informed management decisions. At this point in time there is clear market failure in providing this "on farm" advice (NACC 2005).

Research into the area of NRM adoption has been limited in terms of identifying the farm's physical capacity for adoption. Focus should be firstly on the actual farm's capacity to undertake NRM rather than grower's capacity to adopt. The emphasis on the later may explain the lack of significant uptake of NRM by growers in terms of their already good understanding of environmental problems and strategies. Understanding the degree to which the farm can uptake NRM options based on the trade-offs between production and the actual environmental benefit will influence the grower's willingness to adopt. Being able to quantify the costs and benefits of the proposed situation will help reduce grower uncertainty to the short term consequences of the longer term change. This in term will help the grower understand its effect on the future capacity of the farm business.

### ***The application of precision agriculture technology***

Cook and Bramley (1998) identify the concept of precision agriculture (PA) as a set of crop management methods which recognise and manage within field spatial and temporal variations in the soil-plant-atmosphere system. The practice is to use a range of

technologies such as yield mapping or remote sensing, to identify and explain the spatial variation of yield across a field or farm and apply inputs in a more site specific manner.

Several studies into the use of PA technology in particular yield mapping, have shown that yield and gross margins vary considerably across individual fields (Cook and Bramley 2000, Blackmore 2000, Blackmore et al. 2003). Studies into grain yield over time in Australia routinely show yield ranges of between 0.5 and >4 tonnes per hectare within a single field (Cook and Bramley 2000, Wong and Lyle 2003). These low yielding areas of the field due to the inherent landscape properties, consistently lose money independent of seasonal variations (Wong and Lyle 2003). If this situation holds true, the use of yield mapping will play an important part in helping the grower quantify the specific monetary loss to the farming enterprise. Transferring these areas out of cropping to native vegetation will increase overall farm profits and also provide an environmental benefit. Yield mapping will also recognise areas of profitable production. If management changes are sought in these areas data is available on the profit that the grower will forgo. Providing financial estimates at the sub-field for the whole farm provides the grower with information at a scale which compromised decision making can be achieved. Lyle and Wong (2003) attempted to understand these compromises between farm production and environmental outcomes based on the spatial modeling of financial and environmental tradeoffs in the Wheatbelt of Western Australia. At the farm scale, the reassignment of land based on a compromise between two differing but individually important outcomes showed the loss to grower in terms of profits foregone in the short run in order to gain environmental benefits in the longer term. Although this study was an introductory insight into the way PA technology can help NRM decision-making it shows a possible approach through quantification of both yield and identification of areas where there were imminent environmental problems. The use of PA technology can help understand the degree and capacity to which the farm can change on ground and identify the risks of impact on the farm business from adoption of NRM practices. We believe that this approach has room for further investigation.

### ***Conclusions and discussion***

Growers in the Australian grains industry are under more pressure than ever to adopt NRM practices to combat environmental degradation. A shift of responsibility from the State and Federal governments to local catchment management has placed environmental issues solely at the regional level. The fact that the process of distributing money to the CMAs on completion of an agreed environmental action plan may well place unrealistic targets and evaluation criteria on the farming community. Pressure to adopt NRM practices is also being exerted from the grains industry itself. The industry wants to hold on to the image of 'clean and green' production so as to access niche markets in the future. The industry, national and state farming federations as well as regional farming systems groups all now realise the need to be committed to a triple bottom line approach, with farming practice and good environmental stewardship the key to both short and longer term prosperity. What is important however, are that the environmental and remediation decisions are made at the sub-field, field or farm scale by the grower. These decisions will be made in uncertainty and although farming system groups may help provide some information on what the likely impacts may be, the potential loss to the business will be farm and field specific. This uncertainty in the decision making process will naturally lead to lack of NRM adoption. This lack of adoption has been researched quite thoroughly with the main determinants suggested as economic, individual and social characteristics, as well as institutional factors. We have highlighted that NRM adoption in Australia followed the theory outlined by Gallopín (2002) that willingness, understanding and capacity were major drivers of adoption. The second section of this paper highlighted the different pressure groups which will drive the willingness and understanding of future growers perceptions; whereas capacity is solely left to the individual grower. One area that has had limited research into is the physical capacity of the farm to undertake NRM i.e. what is physically possible in terms of the actual benefit and costs of adopting NRM strategies. The application of PA technology into this area, may be able to help reduce the uncertainty and ignorance in the decision making process by being able to quantify both the short term effect on grower's income and long term effect on environmental degradation. This approach will be looked at in future research.

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## Appendix 2: Program development

### *Graphical user interface*

Figure 51 shows the graphical user interface for the yield map error removal software. Values in the text boxes can be changed by the user. The default values chosen are just examples and while they have been used in the analysis they have not be optimised. Further research is needed to determine the appropriate values for the implemented routines.

The Universal Transverse Mercator (UTM) Zone pull down menu allows the user to select the zone that the yield maps are in so that the latitude and longitude co-ordinates can be transformed into Eastings and Northings. Details of the UTM zones can be found at:

<http://www.ga.gov.au/nmd/products/maps/raster250k/help/helpabout1.jsp>

(Accessed November 2009)



**Yield Map Error Removal Software**

Open Files

UTM Zone: 50  Rinex file

**Moisture measurement**

Minimum (%)

Maximum (%)

**Co-located measurements**

Minimum forward distance (metres)

Minimum lateral distance (metres)

**Grain yield filter**

Yield threshold (%)

Forward/backward search path (number of points)

Smoothing between measurements (number of points)

Input maximum yield (tonnes per hectare)

Concatenate Files

**Delay time and short segment**

Start Pass Delay

End Pass Delay

Short segments (number of points)

**Harvester speed**

Speed threshold (%)

Forward/backward search path (number of points)

Smoothing between measurements (number of points)

**Turns Filter**

Harvester turn angle (degrees)

Swath width (metres)

Search distance between points (metres)

Forward/backward search path (number of points)

Smoothing between measurements (number of points)

**Process**

**Figure 51** The Yield Map Error Removal Software graphical user interface

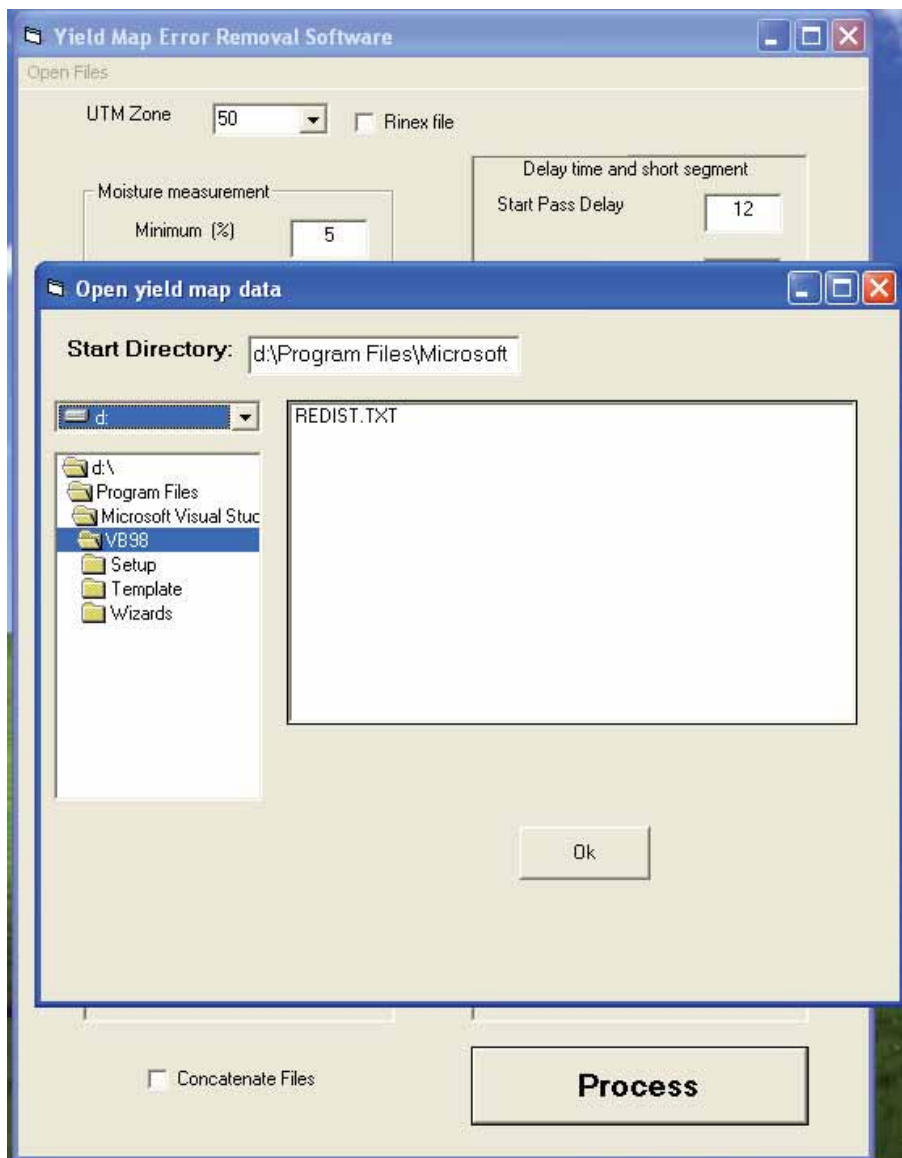
Figure 52 and Figure 53 show the process for opening and selecting yield files with a Windows interface.

The screenshot displays the 'Yield Map Error Removal Software' window. At the top, there is a 'Open Files' tab and an 'Open Yield File' button. Below this, a dropdown menu shows '50' and a checkbox for 'Rinex file' is present. The main area is divided into several sections, each with a title and a list of parameters with input fields:

- Moisture measurement**
  - Minimum (%) : 5
  - Maximum (%) : 15
- Co-located measurements**
  - Minimum forward distance (metres) : 1.5
  - Minimum lateral distance (metres) : 1.5
- Grain yield filter**
  - Yield threshold (%) : 40
  - Forward/backward search path (number of points) : 4
  - Smoothing between measurements (number of points) : 5
  - Input maximum yield (tonnes per hectare) : 8
- Delay time and short segment**
  - Start Pass Delay : 12
  - End Pass Delay : 6
  - Short segments (number of points) : 12
- Harvester speed**
  - Speed threshold (%) : 20
  - Forward/backward search path (number of points) : 5
  - Smoothing between measurements (number of points) : 5
- GPS Correction**
  - Harvester angle : 30
  - Search distance between points (metres) : 10
  - Forward/backward search path (number of points) : 4
  - Smoothing between measurements (number of points) : 5

At the bottom left, there is a checkbox for 'Concatenate Files'. At the bottom right, there is a large button labeled 'Process'.

Figure 52 Opening yield files from the graphical user interface



**Figure 53** Selecting yield files from the graphical user interface

Table 17 illustrates the Ag Leader Advanced file format used as input into the software. Each file must satisfy this format and have the appropriate information for processing to be completed satisfactorily. In this project, early yield mapping on one farm used the Rinex Technology™ system. These files were passed through a routine to add dummy variables to mimic the format needed for when the check box “Rinex file” is selected.

**Table 17 Ag Leader Advanced file format**

Column	Column Heading	Units	Explanation
1	Longitude	Degrees	Geographic co-ordinates
2	Latitude	Degrees	Geographic co-ordinates
3	Mass Flow Rate	pounds or grams	
4	GPS time	Seconds	
5	Logging Interval	Seconds	
6	Travel distance	Inches or millimetres	
7	Nominal Header (swath) width	Inches or millimetres	This is used to determine whether file is in imperial or metric units:
8	Moisture	%	Wet basis
9	Header Status		Bits 0 through 4- header down
10	Pass #		
11	Monitor Serial #		
12	Field ID		Number and name of field
13	Load ID		Number and Name
14	Crop Type		
15	GPS Status		
16	PDOP		Point dilution of precision – measure of GPS accuracy

Swath width is used to determine if a file is in imperial or metric units. Most harvester cutter bars are around 10 metres so if a swath width is less than 550 (around 14 metres) this implies that the measurements are measured in imperial units. These are then adjusted to metric units to produce yield estimates in tonnes per hectare.

An example of the Ag Leader Advanced file format measured in imperial units is shown below, swath width in bold:

```
1XX.096899,-XX.265681,9.90,1131931193,1,68,420,8.0,33,1,138195,"F0:R36","L1:","BARLEY",7,0,105.9
1XX.096919,-XX.265683,10.80,1131931194,1,68,420,8.0,33,1,138195,"F0:R36","L1:","BARLEY",7,0,105.9
1XX.096938,-XX.265683,10.50,1131931195,1,68,420,8.0,33,1,138195,"F0:R36","L1:","BARLEY",7,0,106.2
1XX.096957,-XX.265683,11.70,1131931196,1,70,420,8.0,33,1,138195,"F0:R36","L1:","BARLEY",7,0,106.2
1XX.096977,-XX.265683,11.60,1131931197,1,70,420,8.0,33,1,138195,"F0:R36","L1:","BARLEY",7,0,106.2
1XX.096996,-XX.265683,12.20,1131931198,1,70,420,8.0,33,1,138195,"F0:R36","L1:","BARLEY",7,0,106.6
```

An example of the Ag Leader Advanced file format measured in metric units is shown below, swath width in bold:

```
1XX.885826,-XX.310793,290.00,1164427307,1,3688.00,10899.00,9.00,1,1,121467,"F1: P1","L1: ","Wheat (White)","Yitpi",113.31
1XX.885867,-XX.310793,220.00,1164427308,1,3708.00,10899.00,9.00,1,1,121467,"F1: P1","L1: ","Wheat (White)","Yitpi",113.31
1XX.885909,-XX.310793,230.00,1164427309,1,3688.00,10899.00,9.00,1,1,121467,"F1: P1","L1: ","Wheat (White)","Yitpi",113.29
1XX.885951,-XX.310793,210.00,1164427310,1,3738.00,10899.00,9.00,1,1,121467,"F1: P1","L1: ","Wheat (White)","Yitpi",113.27
1XX.885992,-XX.310793,190.00,1164427311,1,3778.00,10899.00,9.00,1,1,121467,"F1: P1","L1: ","Wheat (White)","Yitpi",113.27
1XX.886034,-XX.310793,200.00,1164427312,1,3778.00,10899.00,9.00,1,1,121467,"F1: P1","L1: ","Wheat (White)","Yitpi",113.24
1XX.886351,-XX.310793,150.00,1164427319,1,4348.00,10899.00,8.80,1,1,121467,"F1: P1","L1: ","Wheat (White)","Yitpi",113.23
1XX.886398,-XX.310793,170.00,1164427320,1,4398.00,10899.00,8.80,1,1,121467,"F1: P1","L1: ","Wheat (White)","Yitpi",113.20
```

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Several sub-routines are used to identify file directory, file name and file manipulations and these are called at the initial and at other times during the program execution. The major procedures used in the software are shown in Figure 54

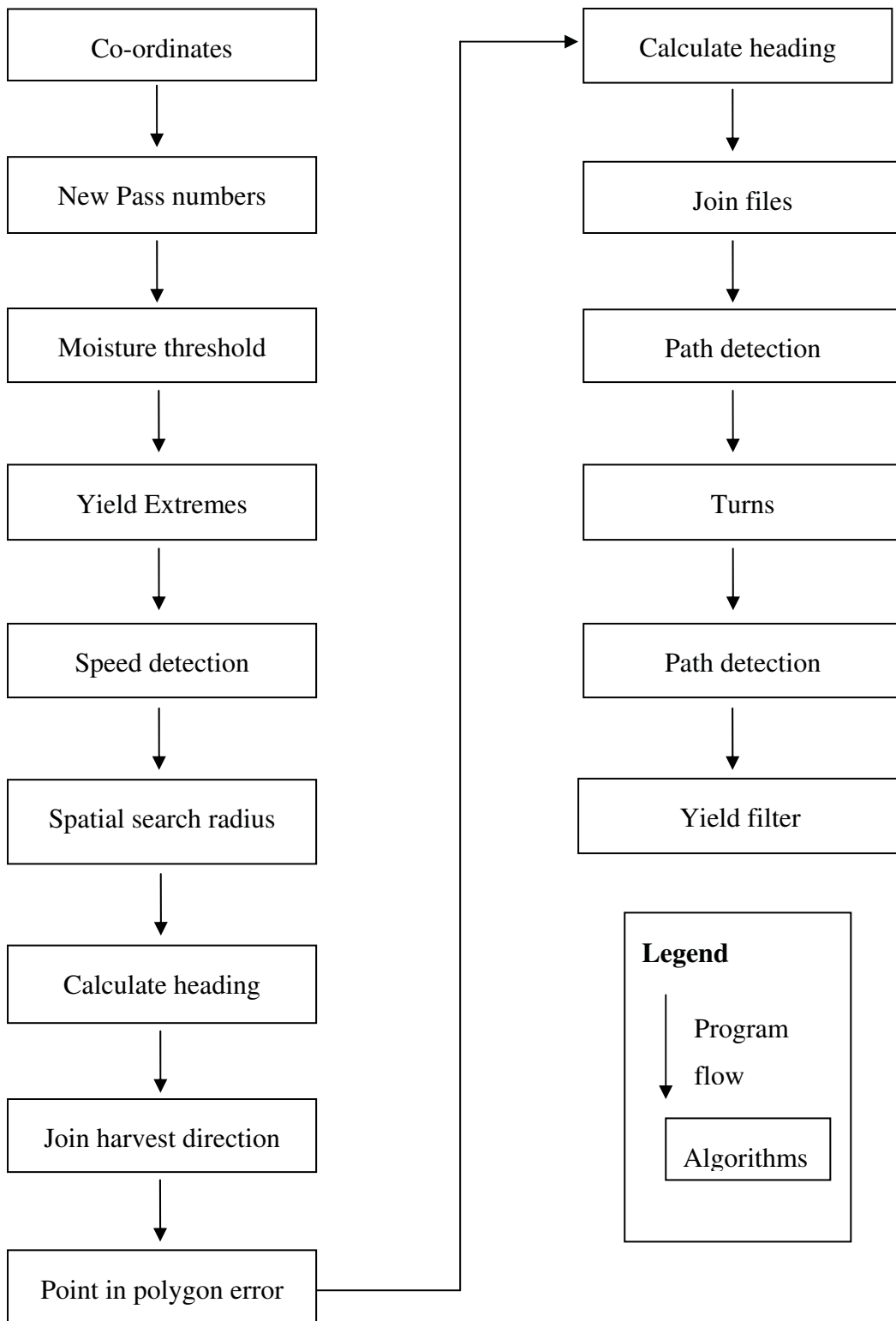


Figure 54 Yield map error removal software program flow chart

### ***Co-ordinates***

The initial procedure called is the co-ordinate conversion routine. Values for Latitude and Longitude co-ordinates are converted to WGS 84 Easting and Northing co-ordinates for the user selected Universal Transverse Meractor (UTM Zone) for Australia using the formulae as defined by the Redfearn transformation published in the National Mapping Council Special Publication 10 - The Australian Geodetic Datum Technical Manual, 1986. UTM definition is GDA-MGA with the GRS80/WGS 84 ellipsoid and is the same for practical purposes as GDA 94. This should be changed to current GDA 94 specifications if further refinements are made.

The new co-ordinate system was tested against and supplied at the same results as an Excel based Redfearn calculator provided by Geoscience Australia (Geoscience Australia, May 2006) available at:

<http://www.ga.gov.au/geodesy/datums/calcs.jsp#trans>

Yield is then calculated. The yield calculation routine takes in two types of raw file settings, the imperial and metric units of measurement. Conversion is made to kilograms and centimetres for processing to yield. For Imperial units flow is in pounds per second and distance and swath width, in inches. For metric units measurements are in millimetres and grams. Program checks for unit conversions.

Below is the formula used:

$$\text{Yield} = (\text{flow} * \text{cycle} / \text{distance travelled} * \text{swath width}) * \text{conversion factor1}$$

Changes made within file:

Distance needs to be changed to from centimetres to square metres and then hectares~  
1 ha = 10,000 square metres = 100\*100 \*10,000

Flow needs to be changed from kilograms to tonnes (1 tonne = 1,000 kilograms)

Conversion factor1= 100,000



Speed of the harvester is also calculated:

$$\text{Speed} = \text{distance travelled} / \text{logging cycle} * \text{conversion factor2}$$

Conversion factor2 = 0.036 – cm/sec to km/hr

Dry grain yield is calculated as:

$$\text{Dry Yield} = \text{yield} - (\text{Moisture measurement} / 100 * \text{yield})$$

Harvester distance travelled between records:

$$\text{Distance} = \text{distance travelled in metres (centimetres to metres)}$$

A dataset which represents the initial unprocessed file is outputted with the following file header and corresponding information:

***Easting,Northing,Yield,DryYield,Moisture,GPS,cycle,Distance,Pass,Elevation,Speed***

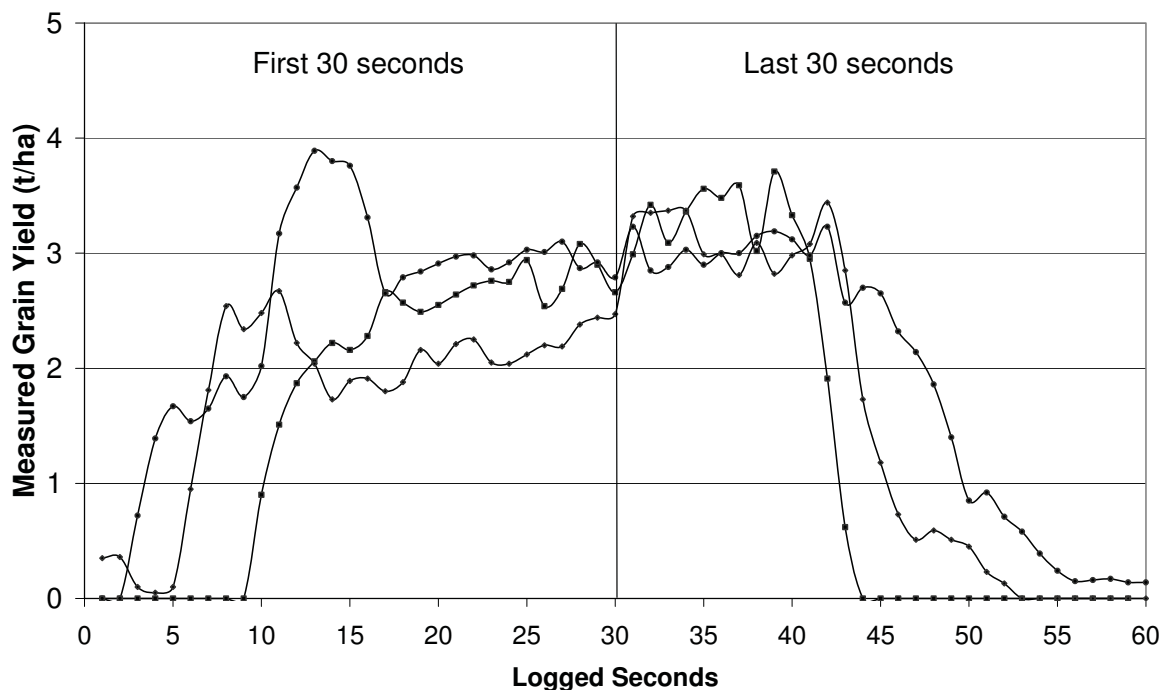
### ***New pass numbers***

An algorithm is run to create new pass numbers. Unique pass numbers are recorded when a new harvest path is commenced with the lowering of the cutter bar. The purpose of this routine recounts the pass numbers to give them a unique ID, since pass number may reset randomly or depending on the system used may not be available.

Pass numbers are not available for RINEX system. A routine was implemented to create a unique pass number based on GPS time of consecutive measurements. A pass number was recorded if the difference between the consecutive GPS time readings was greater than 5. The routine also deals with GPS resets that occur time to time so a routine creates new unique GPS time values based on previous values and the GPS logging time. This routine is enabled with selection of RINEX file check box.

By identifying unique pass numbers, the records that made up a harvest pass were distinguished through a unique incremental counter. The total records that made up the harvest pass were also calculated. Within the harvesting track, erroneous data is collected

at the start and end of each harvest pass (Figure 55). These errors are typified by low grain yield estimates in the first 12 and last 12 seconds of a harvest path. These are called start and end pass delays. Start and end pass delays associated with the harvest passes can be identified and removed based on the unique incremental identifier within a harvest pass. Therefore if a user, via the graphical user interface, identified the first 12 records as being erroneous then records 1 to 12 were removed. A similar reverse situation was used for the end pass delay where the total number of records in the pass was used to identify the last user specified records. As the number of erroneous data points making up start and end delay errors are never constant within a file, harvest tracks made up of a small number of measurements (short segments) were removed based on the total number of records being less than the user inputted value.



**Figure 55** Grain yield in the first and last 30 seconds of continuous yield monitoring for three randomly selected harvest passes

### ***Moisture threshold***

The file is scrutinized for moisture values that comply with a range set by user input of minimum and maximum moisture values. File is iteratively searched to identify measurements that are less than minimum or greater than the maximum and these

measurements are removed. A new file is created with valid moisture measurements. The default moisture measurements range is set between values of 5% to 15%.

### ***Yield extremes***

The file is scrutinized through an iterative search to remove yield values that are over a user inputted maximum value. Default is set to 8 tonnes per hectare. A new file is created with records over the maximum removed.

### ***Speed correction***

The algorithm for speed correction is used to detect fluctuations in the speed of the harvester. The algorithm takes into account both the forwards and backwards average speed of measurements from a particular point. The user inputs a search radius for the number of records that can be searched both forwards and backwards. The default is set to 5 measurements, both forwards and backwards (total of 10 points). Speed of the harvester is then averaged over the search radius for backwards and forwards direction. A speed threshold is also asked of the user given, in percent (default is 20%) of how much the speed can increase and decrease over the search radius. Each record's speed measurement is then compared to the averaged forwards and backwards speed plus the threshold to indicate if it is a speed fluctuation. If the current speed measurement doesn't meet the criteria then the harvester is either slowing down or accelerating. The following criteria, rules and values are given to each measurement to determine speed fluctuations:

- Within the range of  $\pm$  default threshold (20%) of the average forwards and backwards velocities, a value of 0 is given.
- In terms of the backwards speed of the harvester, if value is less than the backwards threshold a value of 1,000 is given indicating that the harvester is slowing down compared to previous speeds. If it is greater than the maximum backwards speed then a value of 2,000 is given indicating that it is speeding up and quicker than the previous speeds.
- In terms of the forwards speed of the harvester, if the speed of the harvester is less than that of the following records the harvester will be slowing down and a value of

10,000 is given. If the current speed is greater than the ensuing records then the harvester is slowing down a value of 20,000 is given.

- If the harvester speed is either greater or less than the both the backwards and forwards average speeds then a value of 100,000 is given.
- A smoothing filter is then run over the datasets looking for measurements that pass the test criteria within an identified speed change. A user inputted number of measurement, set at 5, is searched and where this occurs the program assigns the value of 6 to the record.

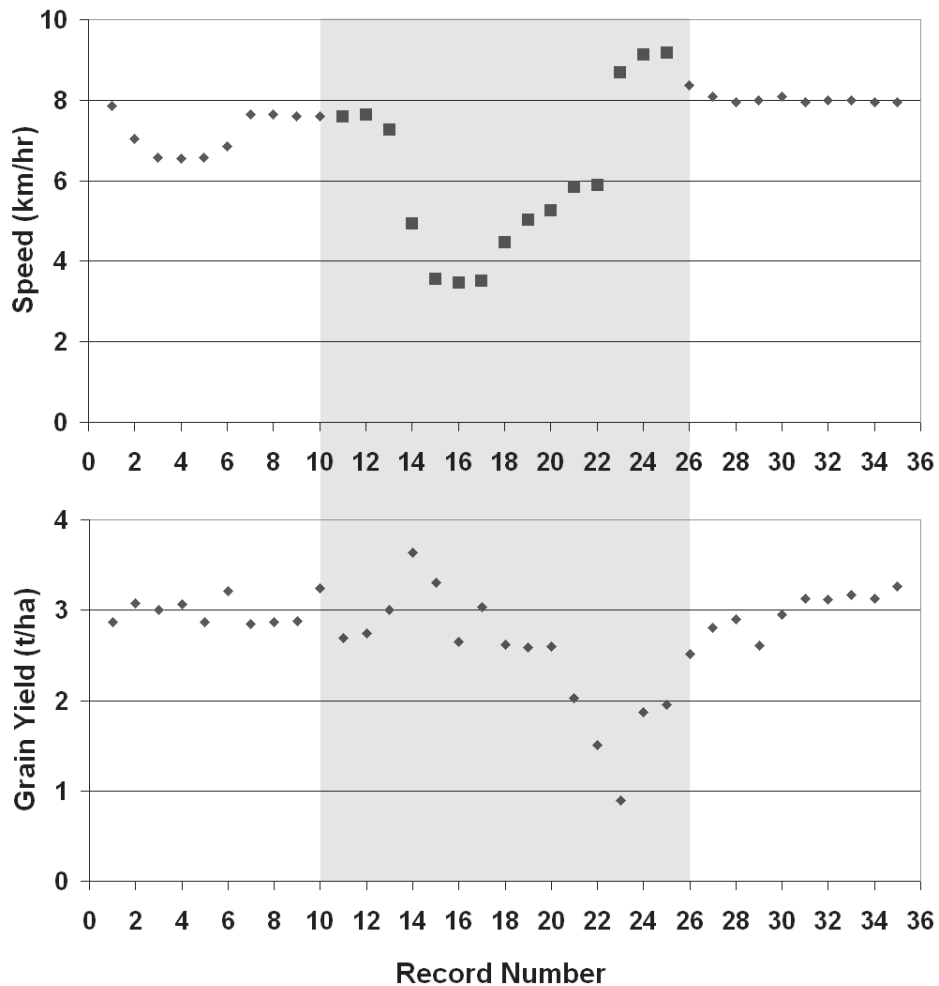
Values at the start and end of a harvest path only take in forwards or backwards measurements. The amount of records used in the calculation of average speed also is determined by the record number within the harvest pass. For example, record 3 within a pass will take in all forwards records and only 2 backwards records to calculate average backward speed. Table 18 shows the range of values associated with the run. At point 5 we see that the 4 point radius can be satisfied with the current speed fitting in between both the backwards and forwards average speeds.

Table 18 Example of harvester speed errors

Records	Yield	Dist	Speed	For_speed	Back_speed	Speed_error
1	2.87	4.37	7.86	6.68	7.83	0
2	3.08	3.91	7.04	6.64	7.84	0
3	3	3.66	6.58	6.9	7.64	0
4	3.07	3.63	6.54	7.18	7.34	0
5	2.87	3.66	6.58	7.43	7	0
6	3.21	3.81	6.86	7.61	6.68	0
7	2.85	4.24	7.64	7.6	6.64	0
8	2.87	4.24	7.64	7.6	6.9	0
9	2.88	4.22	7.59	7.52	7.18	0
10	3.24	4.22	7.59	6.86	7.43	0
11	2.69	4.22	7.59	5.86	7.62	20000
12	2.74	4.24	7.64	4.81	7.6	20000
13	3	4.04	7.27	3.88	7.6	20000
14	3.64	2.74	4.94	3.76	7.52	121000
15	3.3	1.98	3.57	4.12	6.86	1000
16	2.65	1.93	3.47	4.57	5.86	111000
17	3.03	1.96	3.52	5.16	4.81	111000
18	2.62	2.49	4.48	5.51	3.88	6
19	2.59	2.79	5.03	6.42	3.76	112000
20	2.6	2.92	5.26	7.4	4.12	112000
21	2.03	3.25	5.85	8.23	4.57	112000
22	1.51	3.28	5.9	8.85	5.16	10000
23	0.89	4.83	8.69	8.7	5.51	2000
24	1.87	5.08	9.14	8.4	6.42	2000
25	1.95	5.11	9.19	8.1	7.4	2000
26	2.51	4.65	8.37	8.04	8.23	0
27	2.81	4.5	8.09	8	8.85	0
28	2.9	4.42	7.96	8.01	8.7	0
29	2.61	4.44	8	8.01	8.4	0
30	2.95	4.5	8.09	7.98	8.1	0
31	3.13	4.42	7.96	7.98	8.04	0

32	3.12	4.44	8	7.98	8	0
33	3.17	4.44	8	7.99	8.01	0
34	3.13	4.42	7.96	8.2	8.01	0
35	3.26	4.42	7.96	8.42	7.98	0

The first 10 records do not indicate an error even with a small fluctuation because it does fall between the 20% change criteria. It is not until point 11 that the average speed forwards decreases as seen in Figure 56.



**Figure 56** Harvester speed changes (km/hr) and their affect on grain yield measurements (t/ha). Grey area indicates a speed change with a decrease in speed indicated by an increase in grain yield and vice versa

This holds until the record 13. Point 14 then indicates both a failure of both backwards and forwards criteria in particular, a speed slower than the backwards average and faster than the forwards average indicating that the harvester is going to slow down further. Grain yield increases substantially at this point. Point 15 indicates that the current speed is less than backwards speed. Point 16 and 17 indicate that both the average backwards and forwards criteria are not met with speeds both slower than the average. Point 18 shows that all thresholds are satisfied. This is due to the current speed measurement being between low speeds both backwards and forwards. Points 19-21 show that the harvester's speed slowly increases with an increasing speed over the backwards average and still lower than the forward. Point 22 shows that the current speed is only less than the forwards and indicates that the harvester speed will be increasing further. Points 23-25 indicate that the speed is still increasing from the previous backwards speed and has not yet reached a constant speed. With this increase in speed, grain yield decreases. Points 26-35 satisfy the threshold backwards and forwards values. Although the algorithm depends on the user inputted average, a 4 point search radius (in this case 8 seconds) this can be changed for longer speed ranges. A smoothing filter was added to cope with occurrences such as point 18 where the harvester may stay at a constant speed (either low or high) for a period of time. The search is done between where a speed error commences and where it finishes. The algorithm takes in up to 5 points (set by the user) that satisfy both the forwards and backwards criteria between the identified speed changes. Records that are apart of an acceleration or deceleration event are removed. A new file is created without rapid speed changes.

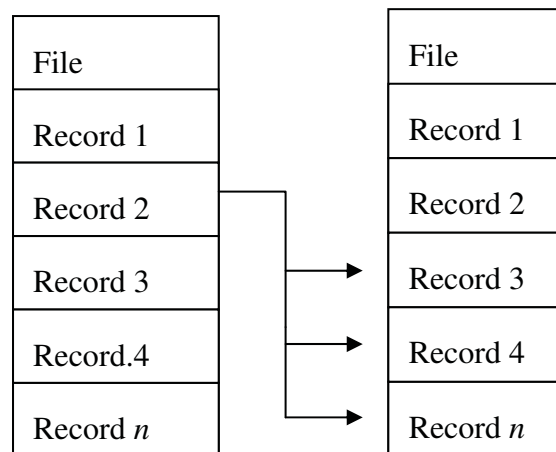
### ***Spatial search radius***

This procedure removes points that are either co-located or in close proximity of each other. The routine involves the creation of two arrays to hold co-ordinates of the yield file, X and Y. GPS numbers were not used due to cases of the GPS resetting or providing GPS values less than those at the start time in certain files. A counter was established to record the measurement number. This assumes that raw data will be used and no sorting is done on the file before correction. By using the record counter we assume that the placement of records within the file represents the actual time of harvest. That is, an earlier recorded

measurement represents the actual area harvested and those later recordings over the same area or in close proximity, measured by their spatial co-ordinates, are overlaps.

Buffer distances are then taken from user input on the graphical user interface. These are set to 1.5 metres around the yield measurement as the default. At this point we do not know which way the harvester is travelling, so a 1.5 metre buffer is placed around each point.

The first record of the file is considered not to be an error. The algorithm iteration structure is designed to start at the first record and loop through to the end of the file to determine which records are within the user inputted buffer distance (Figure 57). Subsequent records are then iterated through (Figure 57) in a forward search pattern since previous iterations will determine if the current record is with the buffer distance.



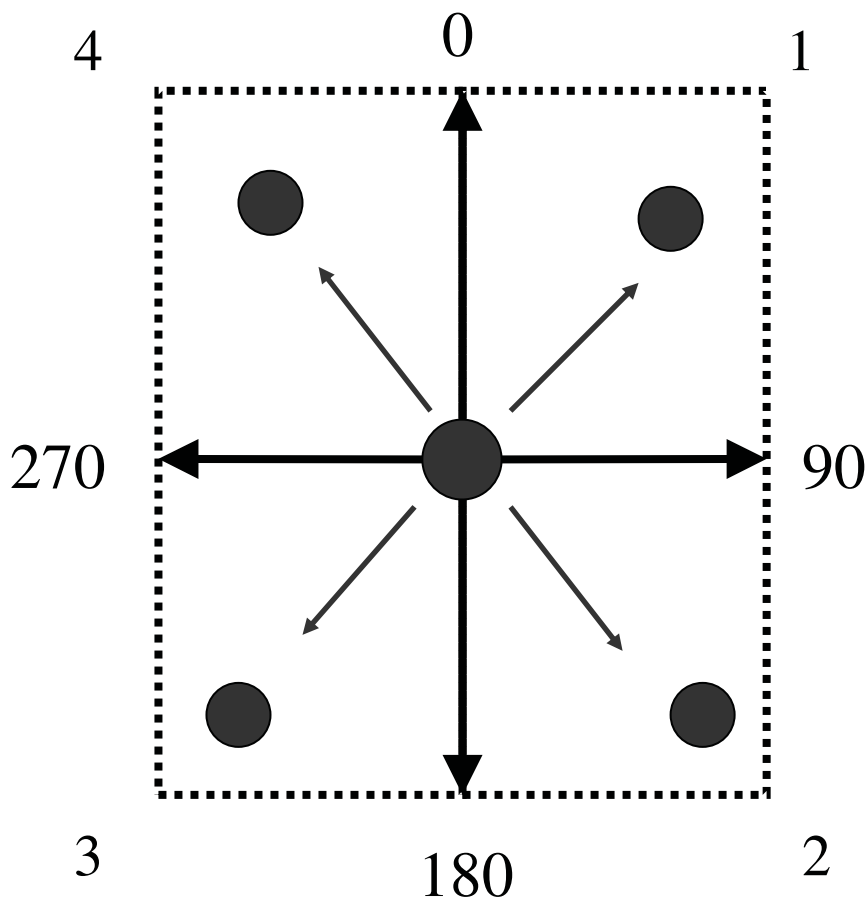
**Figure 57** Interactive file search for co-located or measurement recorded within the default search distance

If a neighbour is found within the buffer distance then its record number is written to an array. All values that are not a spatial error are given a value of 0 while others are given a value of 1. The structure of the algorithm initially gives each value either a 0 or 1 compared to the first record (i.e. within the buffer distance or not). If a value is found to be within the buffer distance a value of 1 is given to the array and the position of the record which is being searched on is also taken. When the next iteration is passed through the search algorithm, measurement given the value of 1 will be skipped and will be removed when a new file is written out.



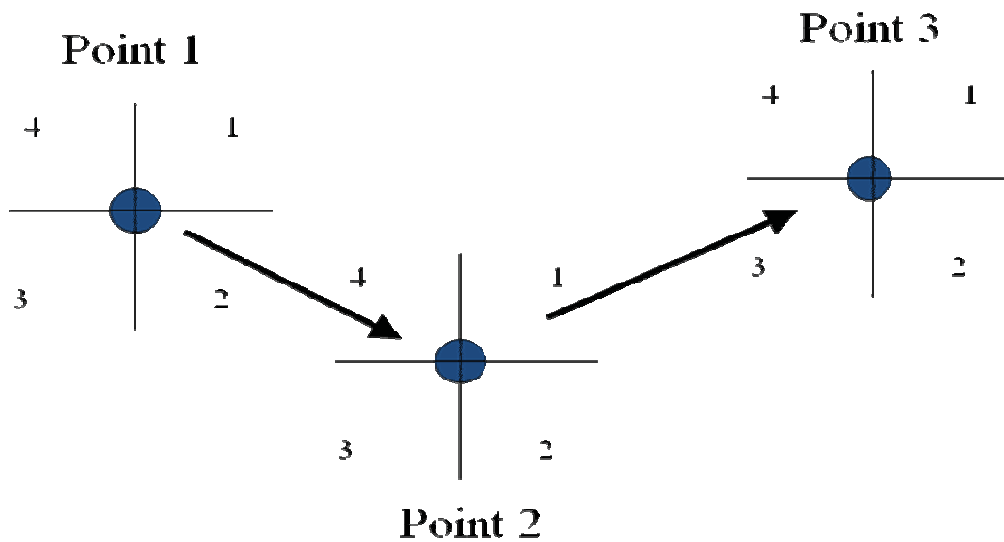
### *Calculate heading*

This routine calculates the harvester travel heading. The true north heading structure was used to identify a common direction of travel. Figure 58 shows the structure used to derive the true north direction between consecutive points. Here, the point in the middle of the figure can travel in a 360 degree direction with a value of 0 representing the true north. For each point, the true north direction was calculated from one point to the next subsequent point. Direction of travel was also given a quadrant number 1 to 4 which will be used to identify direction of travel rules.



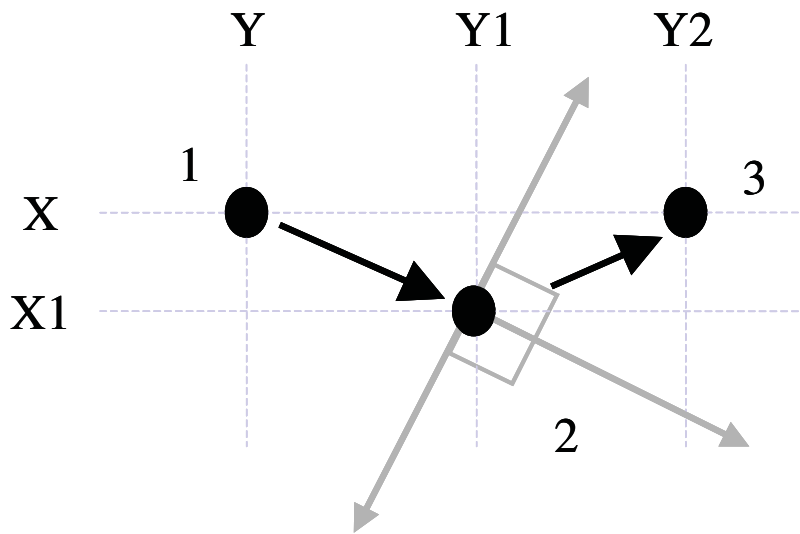
**Figure 58** The structure used to calculate true north direction with 0 equal to true north and direction of travel quadrants 1-4

Figure 59 shows the direction of travel using the quadrants, direction of travel from point 1 to point 2 is in quadrant 2 and direction of travel from point 2 to point 3 is in quadrant 1.



**Figure 59** Example of direction of travel between points 1 to 3

In the initial case, the major assumption is that the heading between point 1 and point 2 is correct. To determine whether the harvester is moving forward a third point is added and heading calculated (Figure 60). The two headings are then compared to see if they are within a user defined threshold value (by default this is set to 90 degrees) from the previous heading.



**Figure 60 Calculation of true north direction between three consecutive points within the user defined threshold (90 degrees)**

To determine harvester direction, Pythagoras's theorem is used to calculate the distance and angle between two measurements. A distance threshold of 10 metres was used to terminate the local neighbourhood comparison process. To determine this distance, it was assumed that the average speed of the harvester was about 3m/sec and that this incorporated around 3 points. Any distance greater than this value represented a start of a different harvest path. Logging time will effect this measurement as a 2 second log time will have a greater distance than a 1 second log time and this will need to be considered by the user when setting the distance threshold.

The quadrants and the co-ordinates of the consecutive points are used to identify changes in Easting and Northing values (Figure 61). The theorem is then used to calculate the changes (Figure 62). To work out angles,  $\tan = \text{opposite} / \text{adjacent}$  is used. For quadrants 1 and 3, the change in x (opposite) and change in y (adjacent) is calculated while, the reverse, change in y (opposite) and change in x (adjacent) is used for 2 and 4.

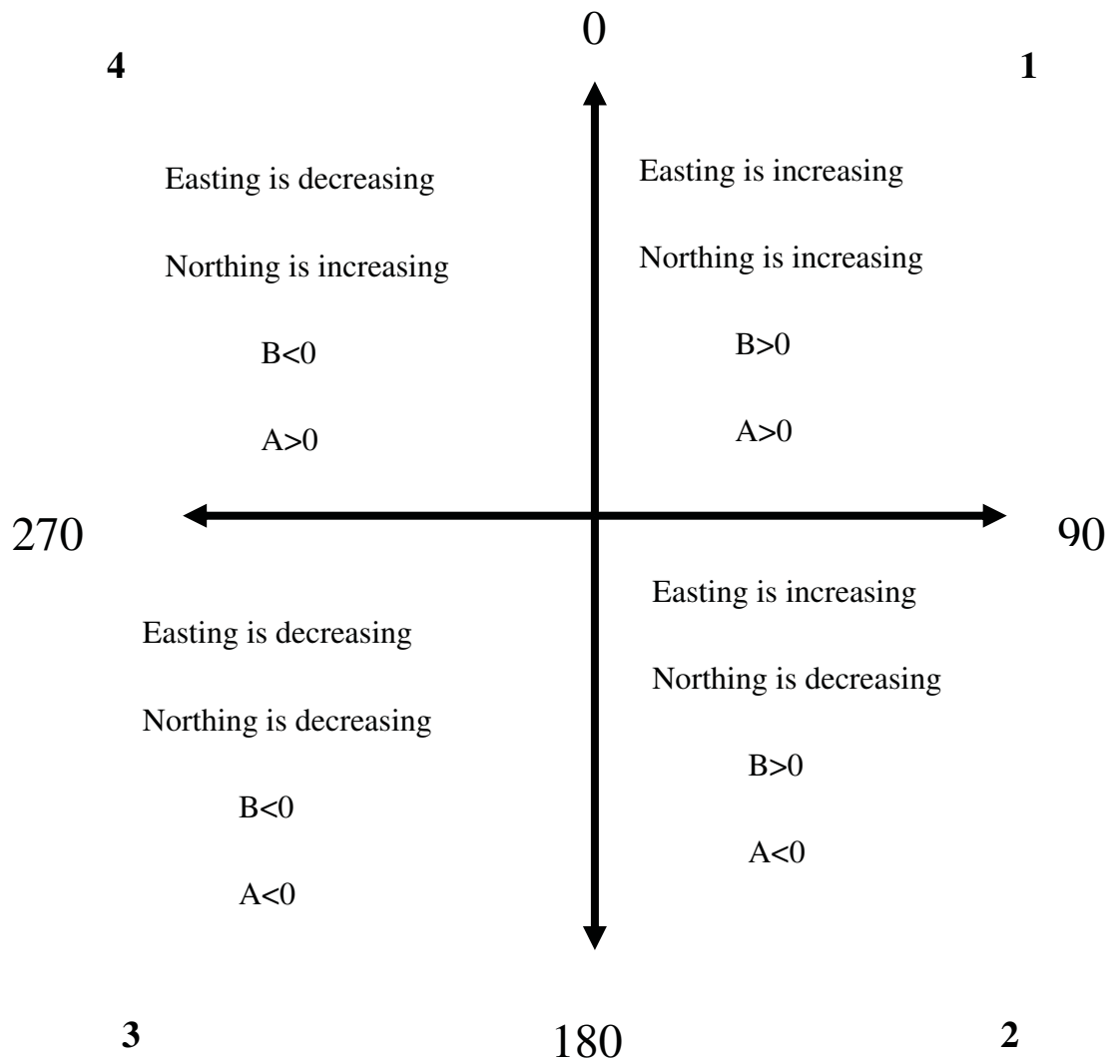
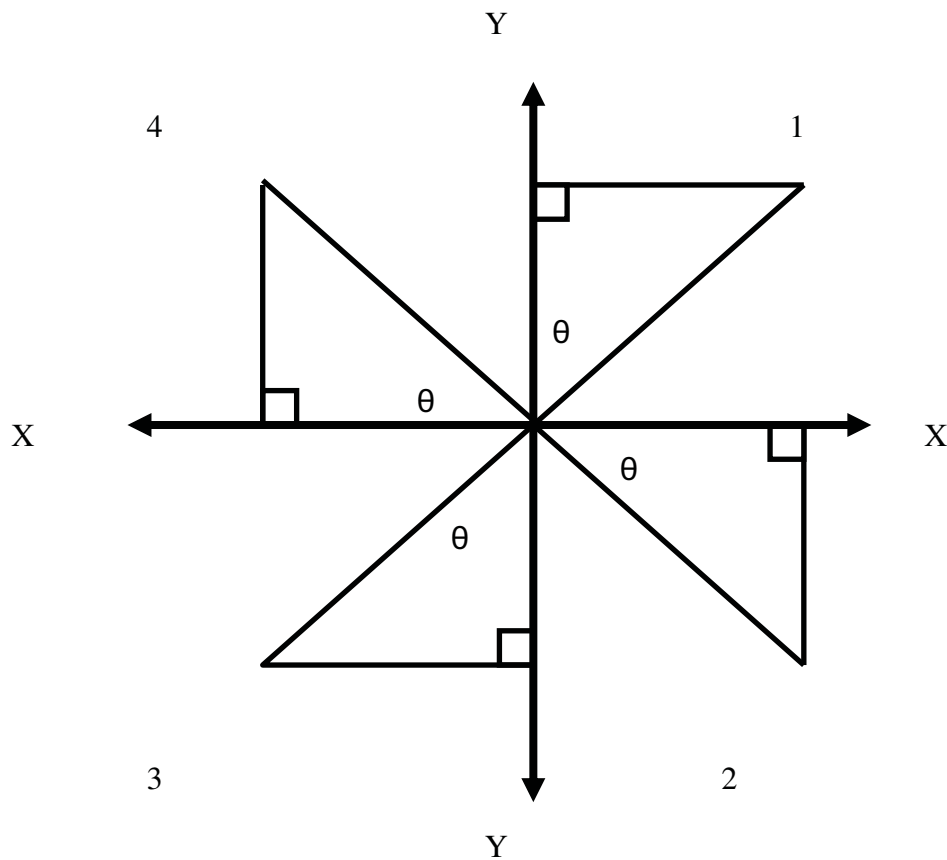


Figure 61 Rules used for deriving true north direction and travel quadrant



**Figure 62 Framework to determine direction angles within quadrants 1-4**

In order to keep the angle within the true north framework, offsets are added. Table 19 highlights the calculations made and the derivations of the true north headings for the subsequent increases and decreases in values in the quadrants. Four other scenarios can occur and these are when there are no changes in co-ordinates. Therefore angles are equal to 0, 90, 180 or 270 degrees.

**Table 19 Rules to apply angle offsets to keep true north direction**

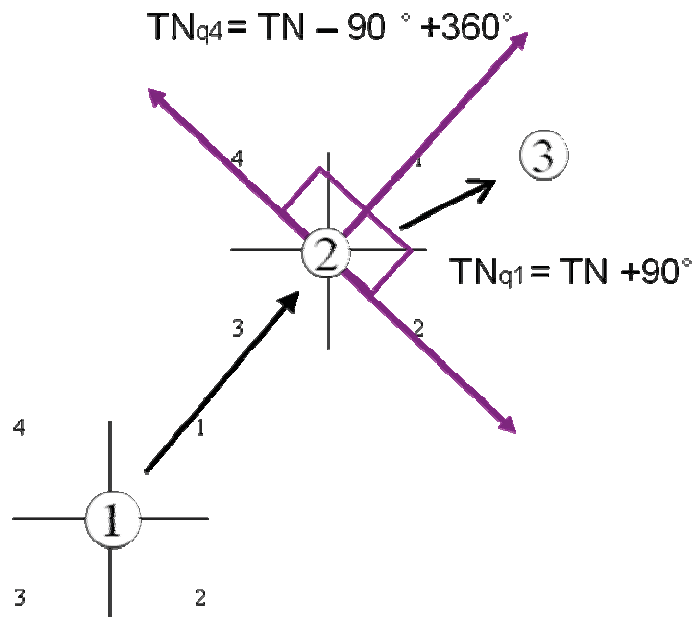
A	B	Angle	True North Heading	Heading
>0	>0	Tan (b/a)	Angle*180/PI	1
<0	>0	Tan (a/b)	Angle *180/PI + 90	2
<0	<0	Tan (b/a)	Angle*180/PI + 180	3
>0	<0	Tan (a/b)	Angle*180/PI + 270	4
>0	=0		0	0
=0	>0		90	90
<0	=0		180	180
=0	<0		270	270

Certain criteria are used to identify points that are logged backwards. If the harvester is moving in the heading directions highlighted in column 1 of Table 20 then the next point cannot be in column 2, this insinuates that the harvester has traveled backwards in the next point. The quadrants are then used to identify the bounding directions using a mixture of angle thresholds to identify GPS error (Table 20).

**Table 20 Rules for quadrants to identify backward points**

Travelling into Quadrant	Backward Quadrant	Next measurement heading	
		True North (TN) Heading1	True North (TN) Heading2
1	3	TNq2: TN heading + user input	TNq4: TN heading – user input + 360
2	4	TNq1: TN heading – user input	TNq3: TN heading+ user input
3	1	TNq2: TN heading – user input	TNq4: TN heading+ user input
4	2	TNq1: TN heading - 360+90	TNq3: TN heading – user input
0	2 or 3		
90	3 or 4		
180	1 or 4		
270	1 or 2		

An example of the technique searching for backward positioned measurements is given in Figure 63 where the direction of harvester travel from point 1-2 and point 2-3 is within quadrant 1. Bounding direction for true north heading is derived via travelling rule 1 which defines TN<sub>q2</sub> and TN<sub>q4</sub>.



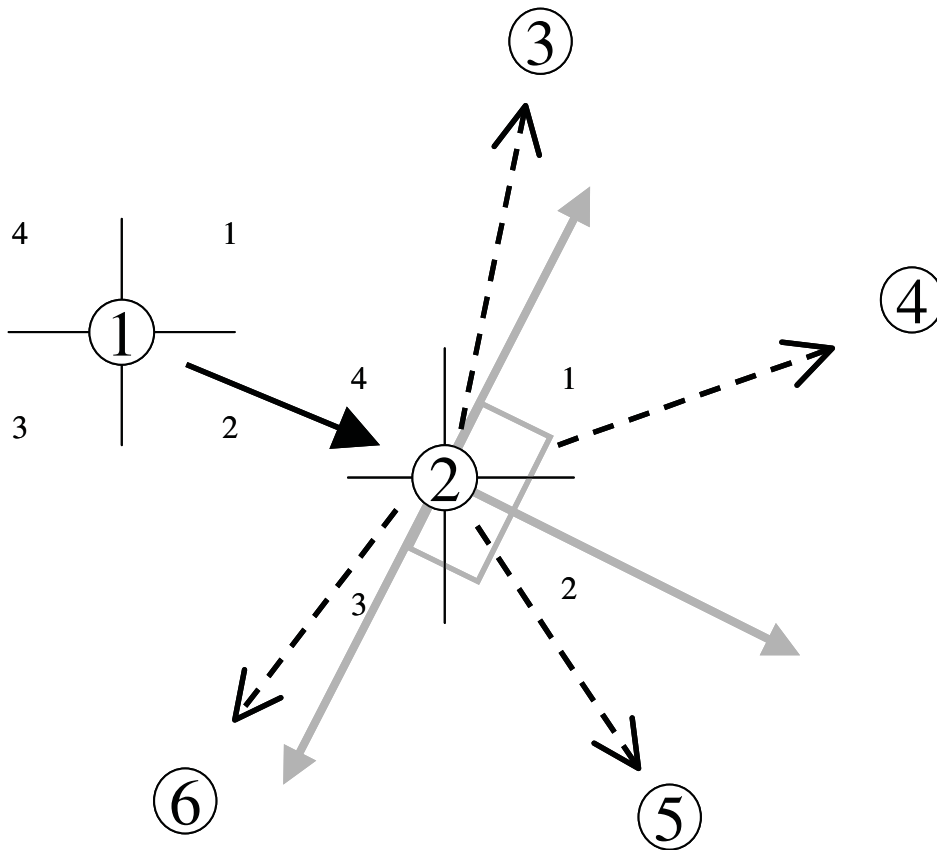
**Figure 63** Example of setting bounding conditions  $TN_{q2}$  and  $TN_{q4}$  based on travel direction into quadrant 1

By establishing a conceptual framework that has a set a common travel direction, identification of backwardly logged measurements is now possible.

Figure 64 shows how backward points are detected. The travel scenarios of point 2 to point 3 and point 2 to point 6 are flagged as error as the location of these points suggests that the harvester has made a very acute turn greater than 90 degrees within the logging period. The location of this point suggests GPS error rather than consistent harvester travel. Points 4 and 5 both fit into the search threshold and therefore are seen as current harvester travel.

For this example the algorithm determines the quadrant in which the harvester is heading, the initial direction of heading from point 1 to point 2 is quadrant 2. If the next direction from point 2 is in quadrant 4, the program will identify this point automatically as a backward point. The algorithm allows GPS recording flexibility in the run of the harvester up until the threshold (90 degrees) either side of the true North heading identified by the rules established in (Table 20).

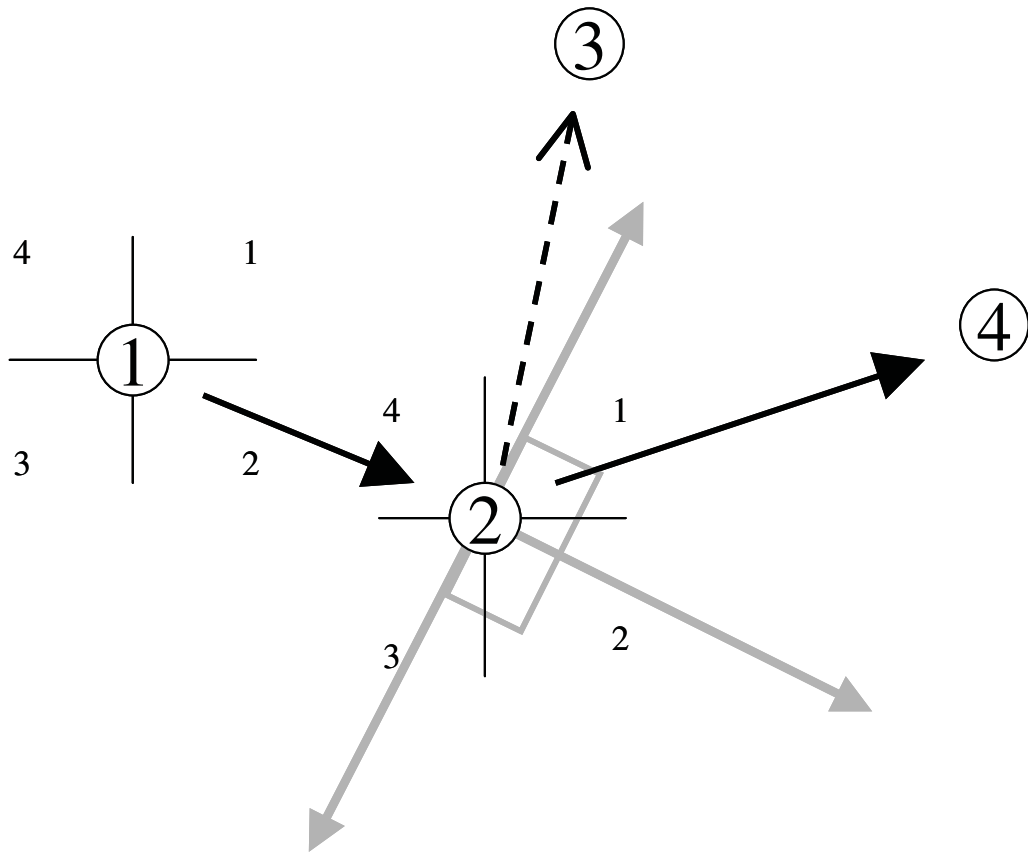




**Figure 64** Search criteria for detecting backward points. Points 4 and 5 pass the 90 degree threshold while points 3 and 6 are classed as GPS error (backward points)

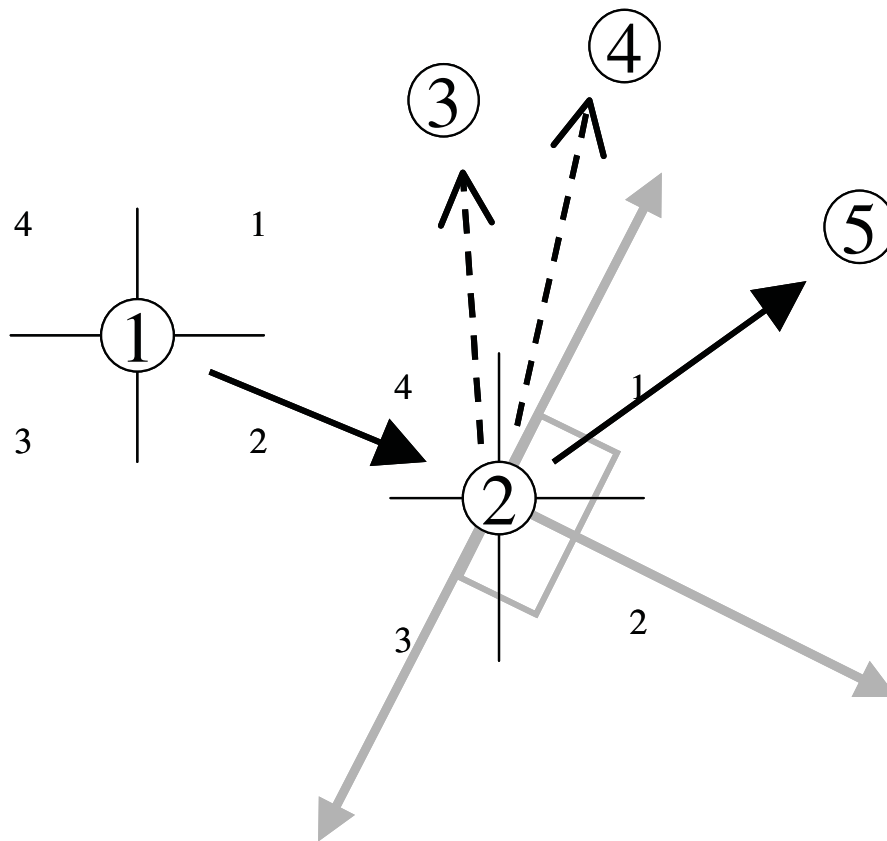
### *Finding a backward point*

The algorithm is always searching one ahead, with the heading of point 1 to point 2 compared to the heading of point 2 to point 3. When the heading between point 2 and 3 fails the threshold condition, the algorithm then selects point 4 as the new heading from point 2. When a backward point is found, the algorithm writes the point out as an error which will be skipped over later. The next record is then examined and when the heading meets the threshold, the record for point 1 is written to file as a valid forward heading.



**Figure 65** Example of finding a backward point. Point 3 identified as a GPS error while point 4 is identified as the path of the harvester

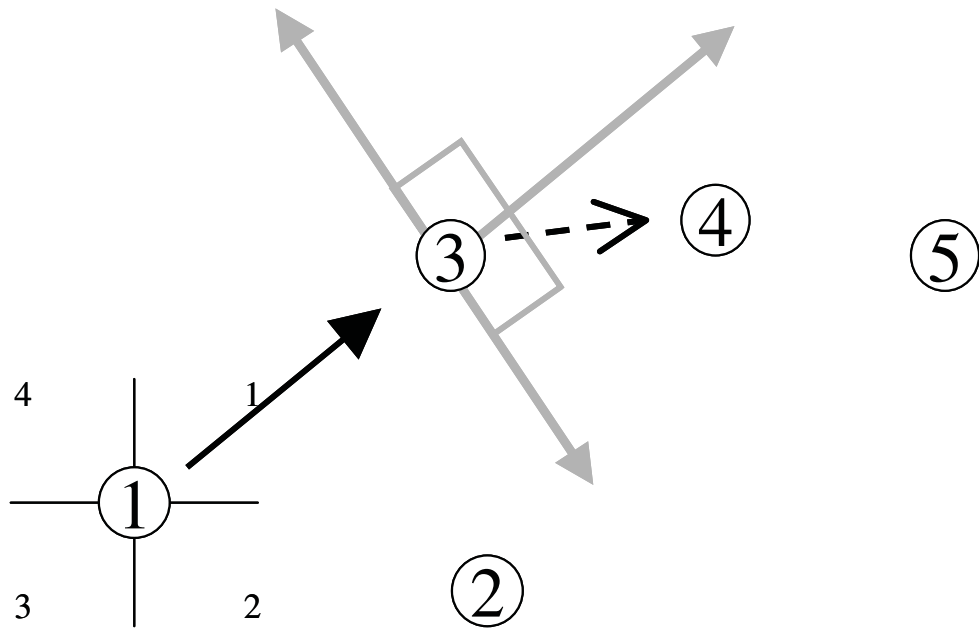
This process may occur multiple times before a forward point is found (Figure 66). Point 3 and 4 fail the two search criteria's, point 3 is within quadrant 4 when the travel direction is into quadrant 2 and the heading of point 4 less than the user based search threshold. Comparisons are made until a forward heading is found (point 5) or the distance between point 2 and the next point exceeds a user inputted threshold (10 metres). This distance criterion terminates the comparison process. Points 3 and 4 are flagged as errors while point 5 is written out as a valid forward heading.



**Figure 66 Example of multiple backward points. Points 3 and 4 fail the quadrant 4 and 90 degree search criteria and are identified as GPS errors. Point 5 is identified as the current harvest travel direction.**

Figure 67 shows when several skips occur and the distance of point 2 to point 5 is greater than the user specified distance. At this stage point 2 is considered to be the error and is written to file indicating this. Point 1, the original starting point, is then orientated to find the heading between point 1 to point 3. The heading between point 1 to point 3 and between point 3 and 4 is then compared to identify a forward heading.

If the distance between point 1 and point 3 is greater than the user specified distance then point 1 is identified as an error and point 3 is the new starting point. The comparison process continues until forward heading is found or the distance criterion is failed.

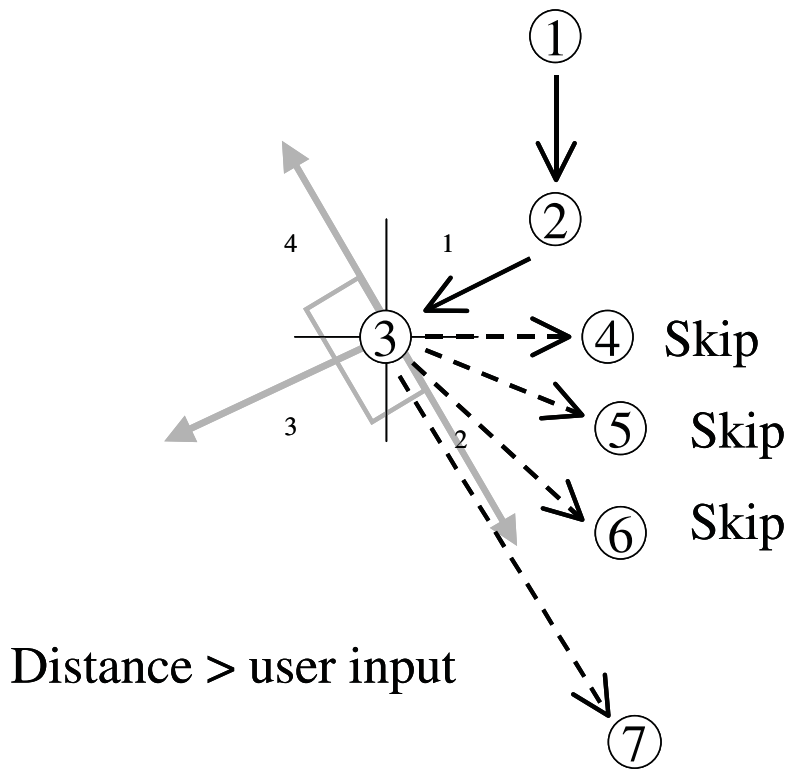


**Figure 67** Example of search criteria where distance between point 2 and point 5 is greater than the user specified distance. Point 2 is identified as an error and point 1 re-oriented to find a new heading between point 3.

To sum up the process several steps can be seen to be undertaken to derive a forward harvest direction, as illustrated from Figure 68 :

1. Distance between point 1 and point 2 is compared, if greater than the user specified distance point 2 is selected as the new starting point.
2. Where distance between point 1 and point 2 is satisfactory, the heading of point 1 to point 2 is compared to the heading of point 2 and point 3.
3. Where distance between point 2 and point 3 is satisfactory, the heading of point 2 to point 3 is compared to the heading of point 3 and point 4. If this fails, point 4 is flagged as an error and given a value of 1 representing a record to be skipped.
4. The heading between point 2 and point 3 is then compared to the heading between point 3 to point 5 and in this case is also identified as an error. This comparison process continues until a forwards heading is derived or the distance between point 3 and the next consecutive record is greater than the user inputted distance threshold.

5. If the distance threshold fails between point 3 and point 7 then point 3 is identified as an error and the heading between point 1 and point 2 is compared to the heading between point 2 and point 4. If this is a forward heading, the record of point 1 is written to file as a correct measurement.
6. If the distance between point 2 and point 4 is greater than the distance threshold then the records of point 1 and point 2 are written as correct values and the heading between point 4 and point 5 is the new starting point.



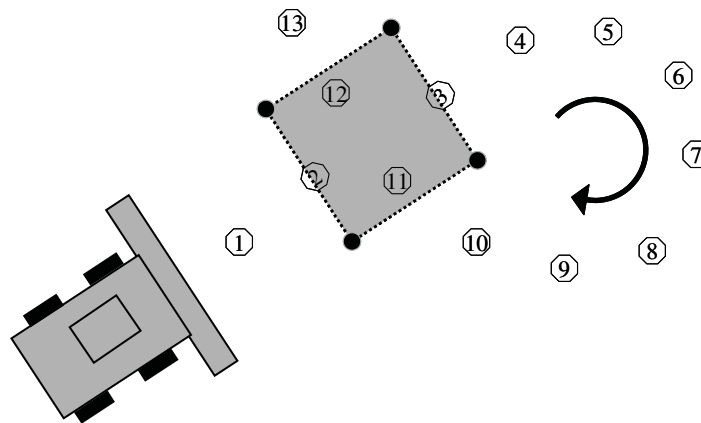
**Figure 68** Example of the process involved in determining backward harvester travel direction.

### *Join harvest direction*

This routine joins heading file with the harvest file together via two arrays that use the values for Eastings and Northings of each measurement as unique identifiers. Skipped records relating to harvester heading differences are removed.

### *Point in polygon routine*

A point in polygon search routine is used to find overlapping measurements. The search routine defines a rectangular search area based on the distance from one point to the next consecutive point and the harvester swath width or cutter bar length represented as a user input set at 10 metres as a default.



**Figure 69** Point in polygon search area defined by the spatial location of measurements with cutter bar length. Measurements 11 and 12 identified as overlaps when search polygon is created between measurements 2 and 3.

In this case, the default is set to 10 metres and this value is halved and assigned to the left and right side of the point measurement to represent the physical dimensions of the cutter bar. The direction of the harvester and the halved cutter bar length is then used to determine the bounding co-ordinates of the search area (search polygon). This is achieved by assigning Sin and Cos rules based on true north offsets derived from the allocated harvest direction quadrant and a degree to radian conversion of 0.0174532925 as shown in Table 21.

**Table 21 Rules associated with deriving bounding point locations for the search polygon**

Quadrant	Search Co-ordinate	Rule
1	Point 1 East	Swath width*sin((heading + 90) *radians)
1	Point 1 North	Swath width*cos((heading + 90) *radians)
1	Point 2 East	Swath width*sin((heading – 90 +360) *radians)
1	Point 2 North	Swath width*cos((heading – 90 +360) *radians)
2	Point 1 East	Swath width*sin((heading - 90) *radians)
2	Point 1 North	Swath width*cos((heading - 90) *radians)
2	Point 2 East	Swath width*sin((heading +90) *radians)
2	Point 2 North	Swath width*cos((heading +90) *radians)
3	Point 1 East	Swath width*sin((heading - 90) *radians)
3	Point 1 North	Swath width*cos((heading - 90) *radians)
3	Point 2 East	Swath width*sin((heading +90) *radians)
3	Point 2 North	Swath width*cos((heading +90) *radians)
4	Point 1 East	Swath width*sin((heading - 90) *radians)
4	Point 1 North	Swath width*cos((heading - 90) *radians)
4	Point 2 East	Swath width*sin(Absolute(360-(heading + 90) *radians))
4	Point 2 North	Swath width*cos(Absolute (360-(heading + 90) *radians))
0	Point 1 East	Swath width*sin(90 *radians)
0	Point 1 North	Swath width*cos(90 *radians)
0	Point 2 East	Swath width*sin(270 *radians)
0	Point 2 North	Swath width*cos(270 *radians)
90	Point 1 East	Swath width*sin(0 *radians)
90	Point 1 North	Swath width*cos(0 *radians)
90	Point 2 East	Swath width*sin(180 *radians)
90	Point 2 North	Swath width*cos(180 *radians)
180	Point 1 East	Swath width*sin(90 *radians)
180	Point 1 North	Swath width*cos(90 *radians)
180	Point 2 East	Swath width*sin(270 *radians)
180	Point 2 North	Swath width*cos(270 *radians)
270	Point 1 East	Swath width*sin(0 *radians)
270	Point 1 North	Swath width*cos(0 *radians)

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270	Point 2 East	Swath width*sin(180 *radians)
270	Point 2 North	Swath width*cos(180 *radians)

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The four co-ordinates are then sorted into minimum and maximum values for Eastings and Northings. It is assumed that for the point in polygon routine, that the 1<sup>st</sup> record harvested and interrogated by the routine is a correctly positioned measurement. The file is then searched sequentially to find measurements recorded within the search area by using the point in polygon equation. A value of 1 is given to these measurements and they are removed when a new file is created.

### ***Join files***

This routine joins the heading file with the harvest file via the unique values for Eastings and Northings of each measurement. Skipped records relating to harvester heading differences are removed.

### ***Path detection***

The process of error removal leaves measurements that are artefacts of the cleaning routines. These can be identified as singular points within the sequential file with no neighbours within a specific distance. The file is searched sequentially and the distance between two consecutive points is calculated. Data is highlighted if values greater than a user specified distance, set at 10 metres, is found. These values are flagged and removed. A new file is then created.

### ***Turns***

To determine a harvester on a turning harvest path the speed algorithm was adapted to take in harvest direction. This routine looked at the forwards and backwards harvest direction of a specified number of measurements provided by the user. The default was set to 4 forwards and backwards measurements. The harvest direction quadrants were used to identify travel in the 1 or 4 quadrant to signify a 360 degree correction. Average forwards and backwards harvest direction over the four points and the differences between the initial and average headings are then calculated. A user inputted threshold, set at 30 degrees is



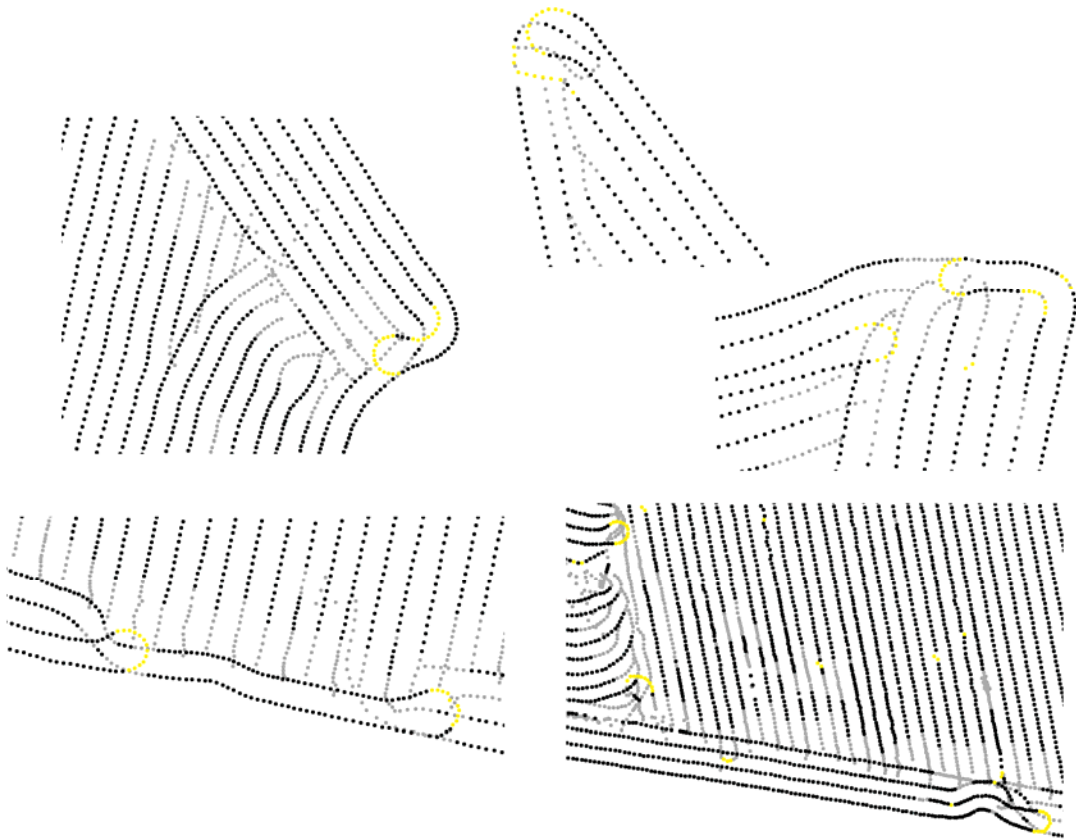
then compared to the difference between the initial and average travel heading. If measurements fail the test criteria values (Table 22) are assigned to each measurement to determine if they are in a forwards direction or within a turn. A smoothing routine is then placed over the dataset to remove measurements that satisfy the test criteria but are part of a turn.

A turn can be defined in a number of ways, namely, when both backwards and forwards criteria fail (value = 3) or a group of test criteria failures (1, 2, 3 and 6). A number of combination of files are produced that have different definitions of turns in them based on Table 22. For example, a file is produced that has forwards directions only, removing measurements that have values, 1, 2, 3 and 6. This file represents a group of measurement that have records coming into a turn, during the turn and coming out of the turn removed.

**Table 22 Assigned values and rules for determining turns**

Values	Rules
0	In a forwards direction
1	Forwards direction identifies this measurements as a turn
2	Backwards direction identifies this measurement as a turn is turn
3	Both forwards and backwards
6	Within a turn but satisfy threshold

Figure 70 represents four randomly selected yield mapped fields with harvest turns. Grey points represent the original unprocessed yield dataset which have been removed by previous routines. Black points represent the yield dataset that are used to identify turns and yellow points represent measurement highlighted by the turn algorithm. Within the figure we see that turns still occur but at a lesser degree than the user selected value. Individual measurements where travel direction is greater than the user assigned value are also highlighted.



**Figure 70** Yield mapping of four randomly selected fields with harvester turns. Grey points represent original yield mapped dataset which have measurements removed by previous routines, black points indicate the dataset where turns are being removed and yellow points represent harvest turns identified by the turn algorithm.

### *Yield filter*

The yield filter algorithm detects and removes local fluctuations in yield measurements along each recorded harvest track. Once again the speed and turn algorithm is used to distinguish erroneous yield measurements from neighbouring average records, both forwards and backwards, within the harvest track. The user defined search radius is set to 4 forwards and backwards measurements. A user defined threshold, with a default set to 40% is then used to determine if the current value falls inside the average value plus the threshold. If measurements fail this test criteria values are assigned (Table 23) to identify local yield fluctuations. A smoothing routine was also implemented to remove measurement that fell between measurements identified as yield fluctuations. A user

inputted value is set (5 measurements) to allocate the amount of smoothing between measurements.

**Table 23 Assigned values and rules for removing yield fluctuations**

Value	Rules
0	Measurement is within average backwards and forwards yield plus threshold
1	Less than backwards average plus threshold
2	Greater than backwards average plus threshold
1000	Less than forwards average plus threshold
2000	Greater than forwards average plus threshold
10,000	Outside backwards and forwards test criteria
6	Yield fluctuation smoothing

Table 24 and Table 25 show examples of two harvest paths, 19 measurements long with yield fluctuations. Table 24 ,Figure 71A and B shows that the majority of measurements fall outside the average minimum and maximum bounds of the forward and backwards thresholds. Smoothing of the yield fluctuation errors are at points 14 and 17. This process continues to highlight yield fluctuations until yield measurements fall within the defined backwards and forwards criteria. Table 25, Figure 71C and D also show where yield measurements fall within the user defined thresholds, fail the criteria and then pass it. From the yield filter value, measurements can be identified when they fail the criteria. Therefore, a particular type of yield fluctuation can be kept or excluded from the dataset. In this study, all yield fluctuation types were excluded and a new file was created.

**Table 24 Example 1 - Yield filter algorithm identification of a large range of yield fluctuations**

Measurement	Forwards	Forwards	Backwards	Backwards	Yield	Yield Filter
	Max	Min	Max	Min		
1	2.405	1.295	1.664	0.896	1.31	0
2	2.132	1.148	1.729	0.931	1.94	2
3	1.664	0.896	1.95	1.05	2.31	12002
4	1.3	0.7	2.223	1.197	1.71	2000
5	1.092	0.588	2.366	1.274	1.45	2000
6	1.222	0.658	2.405	1.295	1.08	1
7	1.482	0.798	2.132	1.148	0.88	1
8	1.794	0.966	1.664	0.896	0.59	11001
9	2.028	1.092	1.3	0.7	0.82	1000
10	1.872	1.008	1.092	0.588	1.49	2
11	1.586	0.854	1.222	0.658	1.65	2
12	1.313	0.707	1.482	0.798	1.55	2000
13	1.235	0.665	1.794	0.966	1.55	2000
14	1.352	0.728	2.028	1.092	1	6
15	1.521	0.819	1.872	1.008	0.79	1
16	1.742	0.938	1.586	0.854	0.72	11001
17	1.794	0.966	1.313	0.707	1.29	6
18	1.742	0.938	1.235	0.665	1.38	2
19	1.69	0.91	1.352	0.728	1.3	0

**Table 25 Example 2 - Yield filter algorithm identification of one specific yield fluctuation**

Measurement	Forwards Max	Forwards Min	Backward s Max	Backwards Min	Yield	Yield Filter
1	1.664	0.896	1.755	0.945	1.44	0
2	1.729	0.931	1.755	0.945	1.36	0
3	1.755	0.945	1.729	0.931	1.29	0
4	1.781	0.959	1.742	0.938	1.2	0
5	1.612	0.868	1.716	0.924	1.28	0
6	1.248	0.672	1.664	0.896	1.54	2000
7	0.845	0.455	1.729	0.931	1.39	2000
8	0.468	0.252	1.755	0.945	1.26	2000
9	0.273	0.147	1.781	0.959	0.79	12001
10	0.39	0.21	1.612	0.868	0.42	12001
11	0.715	0.385	1.248	0.672	0.12	11001
12	1.105	0.595	0.845	0.455	0.09	11001
13	1.534	0.826	0.468	0.252	0.21	11001
14	1.755	0.945	0.273	0.147	0.76	11002
15	1.807	0.973	0.39	0.21	1.12	2
16	1.833	0.987	0.715	0.385	1.3	2
17	1.794	0.966	1.105	0.595	1.56	2
18	1.794	0.966	1.534	0.826	1.41	0
19	1.82	0.98	1.755	0.945	1.3	0

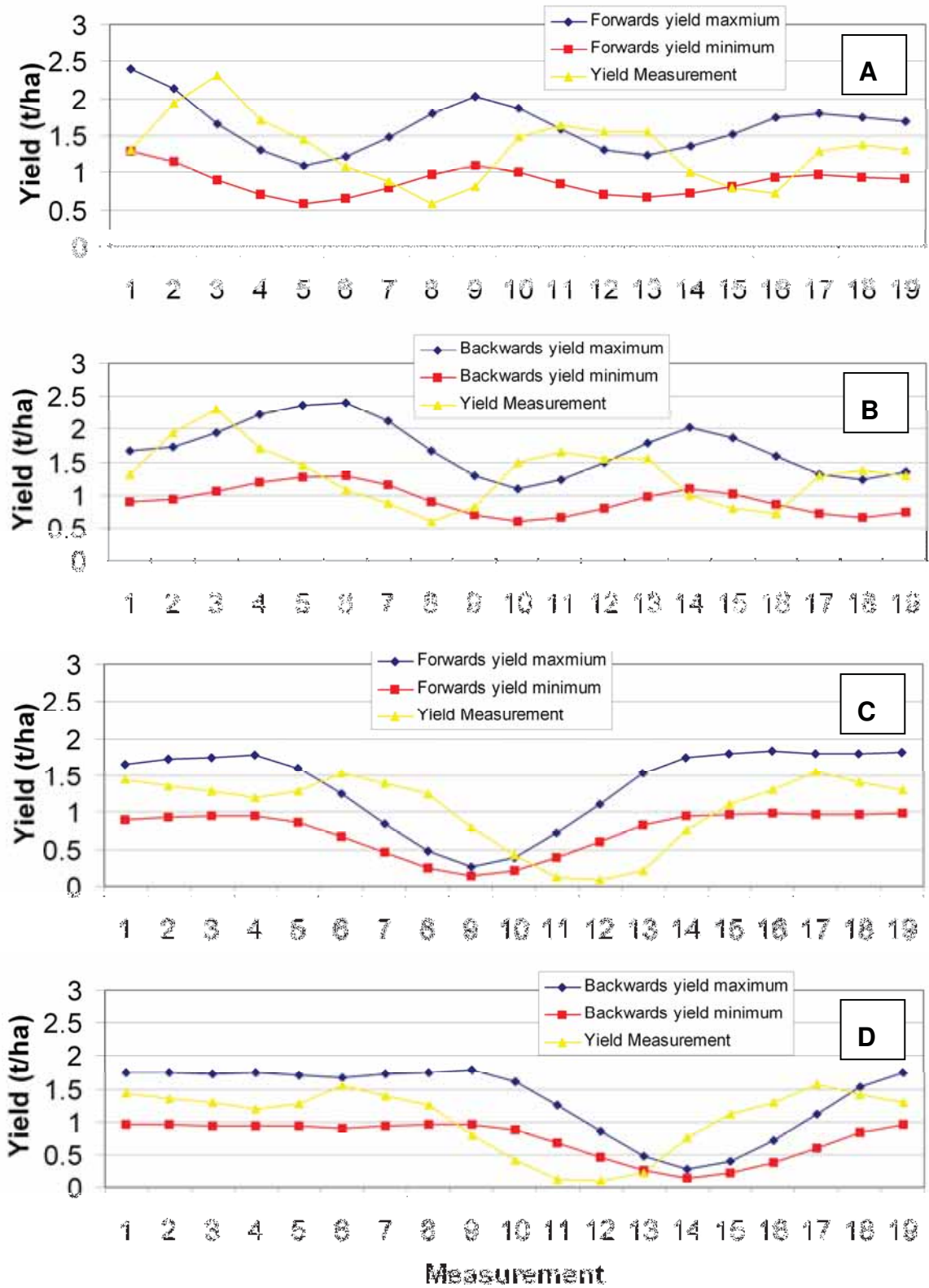


Figure 71 Yield measurements (t/ha) plotted against the average yield for local forwards and backwards neighbourhood for two harvest tracks.

### *Calculation of yield statistics*

At the completion of each error removal process a routine is implemented to derive a variety of summary statistics based on yield (Table 26). This analysis identifies the change in the field yield value with the targeted approach to error removal.

Within a batch processing environment, the concatenate check box allows the user to calculate the average changes in descriptive statistics over the files selected. Two other routines have also been coded into the program. One that removes minimum and maximum values and a standard deviation filter that removes values outside  $\pm 3$  standard deviations of yield. The effectiveness of these simple error removal algorithms can then be compared with the effectiveness of the targeted error routines, in terms of removal of erroneous yield variation.

**Table 26 Summary statistics calculated on each process after completion**

Variable	Summary Statistics
1	Average Yield
2	Standard deviation of Yield
3	Yield Variance
4	Coefficient of variation of yield
5	Skewness
6	Kurtosis
7	Number of measurements with the file