Universidad Publica de Navarra ***Nafarroako Unibertsitate Publikoa***

ESCUELA TECNICA SUPERIOR
DE INGENIEROS AGRONOMOS

NEKAZARITZAKO INGENIARIEN
GOI MAILAKO ESKOLA TEKNIKOA

APLICACIÓN DEL SISTEMA HACCP (HAZARD ANALYSIS AND CRITICAL CONTROL POINT) EN AGRICULTURA DE PRECISIÓN

presentado por

ANGEL GARCIA GARMENDIA*k*

aurkeztua

INGENIERO AGRONOMO
NEKAZARITZA INGENIARITZA

Octubre 2012 / 2012. Urriak

RESUMEN - Aplicación del sistema HACCP (Hazard Analysis and Critical Control Points) en Agricultura de Precisión

Análisis de Peligros y Puntos Críticos de Control (HACCP) es un reconocido método de prevención de peligros para la inocuidad de los alimentos sugerido por Codex Alimentarius. Es un sistema ampliamente utilizado en las industrias alimentarias y se basa en el control preventivo de peligros en todas las fases del proceso en lugar de una intensa inspección del producto final. En agricultura, el sistema HACCP ha sido adoptado para extender la cadena de la seguridad alimentaria desde la industria hasta la producción primaria. Sin embargo, a pesar de considerarse también una herramienta potencial para mejorar la gestión y aumentar la productividad, existen muy pocas referencias, especialmente en producción de cultivos.

Los objetivos, general y específicos, de este trabajo final de carrera son los siguientes:

- ❖ El estudio de la teoría de Puntos Críticos de Control, como herramienta innovadora en la producción de caña de azúcar.
    - ❖ Identificar los peligros más importantes para la producción de caña de azúcar.
    - ❖ Identificar los parámetros clave que deben ser monitorizados.
    - ❖ Identificar los Puntos Críticos de Control del proceso de producción de caña de azúcar.
    - ❖ Averiguar qué lastra a los agricultores la adopción de la Agricultura de Precisión como sistema de manejo.

Este trabajo se realizó siguiendo las directrices en la aplicación del sistema HACCP de la Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO), consistente en un proceso de 12 pasos, adaptado al contexto de la agricultura. Se creó un diagrama de flujo del proceso de producción de caña de azúcar en el que localizar los Puntos Críticos de control. Posteriormente se confeccionaron cuatro cuestionarios para dar respuesta a los objetivos:

- **Cuestionario 1.** Consta de dos listas. La primera enumeró problemas que pueden limitar la productividad de la caña de azúcar. La segunda enumeró los problemas que pueden frenar la adopción de sistemas de precisión. Fueron puntuadas respecto a la severidad y la frecuencia de ocurrencia por expertos y agricultores de distintas zonas geográficas.

- **Cuestionario 2.** Los problemas más importantes identificados en el primer cuestionario fueron enumerados en dos listas nuevamente. Expertos y agricultores sugirieron factores de riesgo por cada uno de los problemas escogidos.

- **Cuestionario 3.** Los factores de riesgo de cada problema fueron puntuados de nuevo respecto a la severidad y frecuencia de ocurrencia.

- **Cuestionario 4.** Los factores de riesgo más importantes fueron seleccionados con las puntuaciones anteriores y se sugirieron Puntos Críticos de Control así como valores límite.

Los resultados identificaron los peligros más importantes que limitan la producción de caña de azúcar y la adopción de tecnologías de precisión por parte de los agricultores, así como sus factores de riesgo más importantes con un consenso moderado.

Los diez factores de riesgo más importantes que limitan la producción de caña de azúcar se engloban en problemas derivados de la cosecha y de la compactación del suelo. Los factores de riesgo que frenan la adopción de la Agricultura de Precisión pertenecen a los problemas derivados del beneficio de su uso y del coste de adquisición.

La atención de estos resultados y su control exhaustivo mediante monitorización con tecnologías de precisión mejorará la gestión y la rentabilidad económica de las explotaciones. Aunque este sistema se aplicará en primer lugar en el cultivo de la caña de azúcar, se espera tenga utilidad en otros cultivos.

AGRADECIMIENTOS

Este Trabajo Final de Carrera ha sido realizado en el National Centre for Engineering in Agriculture, en el campus de Toowoomba, Australia, durante un período de 10 meses. Durante este tiempo, he vivido una experiencia inolvidable y muy intensa, tanto en lo personal como en lo académico. Es por esto que hay muchísima gente que ha tenido un papel fundamental, de la que me acuerdo cada vez que miro atrás y a la que debo agradecer todo lo que han aportado para que disfrutara tanto de esta experiencia.

En primer lugar, mis padres, **Angel y Olga**, han sido quienes me han ayudado en todos los sentidos a conseguir mi objetivo. Sin su apoyo, jamás me habría podido ir al otro lado del mundo. Desde el duro comienzo hasta la revisión final de este Trabajo han estado ahí cada vez que lo necesitaba.

A **Willem Hoogmoed** tengo que agradecer que hiciera las gestiones necesarias para ponerme en contacto con **Troy Jensen**, mi supervisor y compañero en Toowoomba, quien me aceptó para realizar este Trabajo y que tanto se esforzó en que mi estancia en Australia fuera lo más provechosa posible. También quiero mencionar a **Craig Baillie**, director de NCEA, por la confianza que depositó en mí desde mi llegada, darme la oportunidad de ir a varias conferencias y hacer todo lo posible para que regrese con ellos.

No puede faltar la gente con los que compartí esta experiencia, especialmente **Renzo, Marina**, **Lee, Samuel, Alex y Diego**, quienes me dieron los mejores momentos y fueron una gran compañía.

También quiero agradecer a **Luis Miguel Arregui** por su ayuda y esfuerzo en la última etapa de este proyecto, por hacerla lo más organizada y tranquila posible.

ÍNDICE

RESUMEN - Aplicación del sistema HACCP (Hazard Analysis and Critical Control Points) en Agricultura de Precisión i
ÍNDICE v
1. MEMORIA EXTENDIDA 1
1.1 Introducción 3
1.2 Antecedentes 5
1.2.1 Agricultura de Precisión 5
1.2.2 Análisis de Riesgos y Puntos Críticos de Control (HACCP) 5
1.2.3 Caña de azúcar 8
1.3 Objetivos 11
1.4 Metodología empleada 13
1.5 Resultados y discusión 19
1.6 Conclusión 25
2. INTRODUCTION 27
2.1 Precision Agriculture 29
2.2 Hazard Analysis and Critical Control Point (HACCP) 30
2.2.1 PRINCIPLES OF THE HACCP SYSTEM 30
2.2.2 APPLICATION OF HACCP PRINCIPLES 31
2.3 Sugarcane (*Saccharum officinarum*) 34
2.3.1 Background 34
2.3.2 In Australia 34
2.3.3 Planting and vegetative structure 36
2.3.4 Cultural requirements 36
2.3.5 Harvesting 37
2.4 Problem statement 38
2.5 Objective 38
2.6 Research questions 38
3. LITERATURE REVIEW 39
4. METHODOLOGY 47
5. RESULTS AND DISCUSSION 53
5.1 Amended process flow diagram 55

5.2 List of potential hazards (PRINCIPLE 1) ... 56
5.3 Determine Critical Control Points (Principle 2) ... 63
6. CONCLUSION ... 66
7. REFERENCES ... 71
8. ANNEX ... 75
8.1 Questionnaire 1. Interview 1 ... 77
8.2 Questionnaire 1. Interview 2 ... 79
8.3 Questionnaire 1. Interview 3 ... 81
8.4 Questionnaire 1. Interview 4 ... 83
8.5 Questionnaire 1. Interview 5 ... 85
8.6 Questionnaire 1. Interview 6 ... 87
8.7 Questionnaire 1. Interview 7 ... 89
8.8 Questionnaire 1. Interview 8 ... 91
8.9 Questionnaire 1. Interview 9 ... 93
8.10 Questionnaire 1. Results ... 95
8.11 Questionnaire 2. Interview 1 ... 100
8.12 Questionnaire 2. Interview 2 ... 102
8.13 Questionnaire 2. Interview 3 ... 104
8.14 Questionnaire 2. Interview 4 ... 106
8.15 Questionnaire 2. Interview 5 ... 108
8.16 Questionnaire 2. Interview 6 ... 110
8.17 Questionnaire 2. Interview 7 ... 112
8.18 Questionnaire 2. Interview 8 ... 114
8.19 Questionnaire 2. Interview 9 ... 116
8.20 Questionnaire 3. Interview 1 ... 117
8.21 Questionnaire 3. Interview 2 ... 121
8.22 Questionnaire 3. Interview 3 ... 125
8.23 Questionnaire 3. Interview 4 ... 129
8.24 Questionnaire 3. Interview 5 ... 133
8.25 Questionnaire 3. Results ... 137
8.26 Questionnaire 4. Interview 1 ... 148
8.27 Questionnaire 4. Interview 2 ... 149
8.28 Questionnaire 4. Interview 3 ... 150

LISTA DE TABLAS

Tabla 1. Lista de problemas de producción a puntuar en el cuestionario 1 15
Tabla 2. Lista de problemas de adopción de tecnologías de precisión a puntuar en el cuestionario 1 16
Tabla 3. Resultados del primer cuestionario para problemas de productividad 20
Tabla 4. Resultados del primer cuestionario para problemas en la adopción de tecnologías de precisión 20
Tabla 5. Diez factores de riesgo más importantes en la producción de caña de azúcar 22
Tabla 6. Cuatro problemas más importantes frenando la adopción de tecnologías de precisión 22

Table 1. Example of summary table of the hazard analysis (Pardo, Peñaranda et al. 2011)................42
Table 2. The operational steps followed for the conception and development of the Quali'Terre referential (Galan, Aubry et al. 2003). 44
Table 3. List of potential hazards found in a Sugarcane farm (Questionnaire 1).................................56
Table 4. List of technological problems (Questionnaire 1) 57
Table 5.Scorings of the 10 most important problems driving sugarcane production 58
Table 6.Scorings of the 4 most important technological problems. 58
Table 7. Example of a completed second questionnaire for sugarcane production 59
Table 8. Example of completed Questionnaire 2 for the technological problems 60
Table 9. Top ten risk factors for productivity problems..62
Table 10. Top four technological problems constraining the adoption of PA by farmers....................62
Table 11. Selected risk factors to determine their Critical Control Point(s) and alarm value(s) 63

LISTA DE FIGURAS

Figura 1. Producción de caña de azúcar en Australia por región (2009) 3
Figura 2. Aplicación lógica del sistema HACCP..6
Figura 3. Secuencia de decisiones. Fuente: FAO...14
Figura 4. Diagrama de flujo del proceso de producción de caña de azúcar 19

Figure 1. Logic sequence of HACCP application (FAO 2001)..33
Figure 2. Decision tree to identify CCPs (FAO 2001)...33
Figure 3. The cane growing regions on the NE seaboard of Australia 35
Figure 4. Australian cane production by region (Australian Sugurcane Annual 2009).........................35
Figure 5. The sugar cane plant - (a) primary shoot, (b) secondary shoot, (c) sett 36
Figure 6. On-farm food safety system hazard decision tree (Horchner and Pointon 2011)................45
Figure 7. Critical Control Point decision tree(Horchner and Pointon 2011) 46
Figure 8. First process flow diagram 50
Figure 9. Amended process flow diagram of sugarcane production 55
Figure 10. Distribution of number of risk factors suggested by between one and 13 experts in the panel 60

ABREVIACIONES

CCP/PCC	Critical Control Point / Punto Crítico de Control
HACCP	Hazard Analysis and Critical Control Point
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographic Information Systems
GPS	Global Positioning System
IQR/RIQ	Interquartile Range / Rango Intercuartil
ISSCT	International Society of Sugarcane Technologists
NCEA	National Centre for Engineering in Agriculture
PA	Precision Agriculture / Agricultura de Precisión
VRT	Variable Rate Technology

1.MEMORIA EXTENDIDA

1.1 Introducción

La caña de azúcar es uno de los cultivos más importantes de la agricultura australiana. La producción anual oscila entre 32 y 35 millones de toneladas de caña al año (ver Figura 1), obteniéndose entre 4,5 y 5 millones de toneladas de azúcar, de las cuales el 80 % es exportado. Debido a este alto porcentaje, Australia se sitúa como el tercer mayor exportador de azúcar del mundo (Department of Agriculture 2012).

Figura 1. Producción de caña de azúcar en Australia por región (2009)

Este cultivo supone un valor para la economía australiana entre 1.500 y 2.500 millones de dólares australianos (1.200 – 2.000 millones de euros). El producto principal obtenido de la caña es el azúcar moreno y refinado. En total en Australia, hay 4.000 fincas dedicadas a la producción de caña de azúcar y 24 refinerías repartidas a lo largo de 2.100 km de costa, entre Mossman en el norte de Queensland y Grafton en el norte de Nueva Gales del Sur. Alrededor del 95% de la producción total se encuentra en Queensland y el 5% restante en Nueva Gales del Sur. Recientemente, Asia se ha convertido en un destacado importador de azúcar australiano, siendo los mercados más importantes Corea del Sur, Indonesia, Japón y Malasia (Department of Agriculture 2012).

Hoy en día, los agricultores de caña de azúcar en Australia, como muchos otros en otras partes del mundo, se enfrentan a regulaciones medioambientales cada vez más estrictas y al aumento de precios de fertilizantes y demás inputs, por lo que se ven obligados a utilizar los recursos de la manera más eficiente posible (Buresh 2010). Uno de los conceptos que empezó a tomar fuerza en la década de los noventa fue el de la Agricultura de Precisión (AP) (Cox, Harris et al. 1997). Debido a la fuerte influencia de las características del suelo, la profundidad de enraizamiento, la nutrición, la gestión agronómica y la interacción de éstos con el clima (Runge and Hons 1999), la productividad agrícola de la tierra también es muy variable (Bramley 2009). Sin embargo, aún la mayor parte de las actividades agrícolas dedicadas al cultivo de la caña de azúcar se lleva a cabo en fincas rectangulares, de hasta cientos de hectáreas, bajo un manejo uniforme (Bramley 2009). A pesar de que los agricultores siempre han sabido que sus tierras poseían marcadas diferencias en sus características, sin las herramientas adecuadas para cuantificar y tratar esas diferencias debían realizar un manejo basado en la homogeneidad (Cook and Bramley 1998).

Por otro lado, los agricultores están muy ocupados atendiendo los manuales y las especificaciones de todas las tareas que tienen que realizar y la industria no tiene la metodología adecuada para detectar las tecnologías disponibles que mejorarían y facilitarían la gestión y la eficiencia en las parcelas.

A día de hoy, hay multitud de tecnologías que podrían ser inmediatamente implementadas en sistemas de Agricultura de Precisión, pero los agricultores se mostrarán reacios a utilizarlas si no comprenden su utilidad, ni su rentabilidad con los potenciales beneficios obtenidos con ellas. Además, la enorme cantidad de información disponible puede resultar confusa a la hora de identificar las prácticas y los manejos más importantes y cómo implementarlos adecuadamente.

Por tanto, para el Centro Nacional para la Ingeniería en la Agricultura (NCEA por sus siglas en inglés) es una prioridad no sólo lograr un mayor grado de implementación de Agricultura de Precisión por parte de los agricultores, sino tratar de llevar este tipo de manejo más lejos, mediante el uso de un marco de trabajo basado en una metodología lógica, que racionalice y formalice los problemas de producción así como los métodos de actuación ante determinados problemas. De esta forma, se conseguirá identificar aquéllas áreas de la producción en las que sea necesario llevar a cabo investigaciones para recabar información, con una continua mejora del sistema de producción y disminución de las posibilidades de fallo humano.

Este Trabajo Final de Carrera fue presentado en la conferencia de la Asociación Internacional de Técnicos de la Caña de Azúcar (ISSCT) celebrada en Townsville (Australia) en septiembre de 2012. Trata de ser el primer paso en una serie de trabajos que llevarán ese objetivo hasta el final. Por tanto, en este estudio, se intenta esbozar lo que será un futuro marco de trabajo que mejore la gestión y la productividad en la industria azucarera, con visos a su extensión a otros cultivos de importancia económica, tanto en Australia como en cualquier otra parte del mundo.

1.2 Antecedentes

Esta sección tiene como objeto sentar las bases de los conceptos y métodos utilizados en este estudio. En primer lugar, se describe el concepto de Agricultura de Precisión, manejo en el cual se enmarca el Trabajo. Después, se explica el sistema de Análisis de Riesgos y Puntos Críticos de Control (HACCP por sus siglas en inglés), sobre el que se basa este estudio y finalmente se presentan las características de la caña de azúcar, cultivo elegido para investigar los potenciales beneficios en el uso de la metodología HACCP. Además, también se desarrollarán los objetivos perseguidos en este Trabajo Final de Carrera.

1.2.1 Agricultura de Precisión

En la Agricultura de Precisión, los cultivos son tratados como una entidad espacial variable en vez de una unidad homogénea. Al reconocer la variabilidad presente dentro de una misma parcela, la Agricultura de Precisión también trata de explicar y predecir la posible respuesta a determinados inputs según varía en el espacio (Cook and Bramley 1998).

La Agricultura de Precisión es pues, un sistema de manejo aplicable a cualquier input que se pueda controlar. El objetivo general es incrementar las posibilidades de beneficio y disminuir las posibilidades de riesgo. Por tanto, conduce no sólo a una agricultura más responsable sino también a beneficios económicos significativos en algunos casos.

En Australia, el cultivo con mayor implantación en Agricultura de Precisión es el trigo de secano (*Triticum aestivum)*. En estudios recientes acerca del uso de Tecnología de Frecuencia Variable (VRT) en productores de trigo, se observaron beneficios de entre 5,5€ - 17€/ha (Bramley 2009).

Para que la Agricultura de Precisión sea posible, es necesario el desarrollo y la implementación de ciertas tecnologías. Éstas, deben ser capaces de detectar y cuantificar con exactitud la variabilidad en el terreno para realizar el tratamiento adecuado. Recientemente, la cada vez mayor disponibilidad de estas tecnologías, está permitiendo que la variabilidad espacial sea tenida en cuenta. Sistemas de Posicionamiento Global (GPS), Sistemas de Información Geográfica (SIG), mapas de rendimiento de los cultivos, Tecnología de Aplicación Variable de Insumos (VRT) y teledetección son las tecnologías más importantes (Swinton and Lowenberg-DeBoer 2001; Bramley 2009). Por otro lado, el sistema de Análisis de Riesgos y Puntos Críticos de Control (HACCP), comentado a continuación, está siendo utilizado para ayudar en la adopción de técnicas existentes y asegurar que los procesos más importantes que determinan la productividad y la rentabilidad están implementados y rinden con la menor posibilidad de error (Banhazi and Black 2009).

1.2.2 Análisis de Riesgos y Puntos Críticos de Control (HACCP)

El Análisis de Riesgos y Puntos Críticos de Control (HACCP) se define como un sistema científico que, en un proceso, identifica peligros y toma las medidas para su control (FAO 2001). Es un sistema que, en su origen, no fue concebido para la agricultura pero cuya filosofía cada vez más es utilizada en distintos ámbitos para asegurar mayor control en un proceso. Así, en los últimos años se ha venido experimentando su implementación en la agricultura (Aubry et al. 2005; Hegelund and Sørensen 2007; Leifert et al. 2008; Horchner and Pointon 2011), principalmente para garantizar una mayor calidad. Hay también estudios en los que se sugiere la aplicación de este sistema en el sector porcino para granjas de precisión con el objeto de mejorar la productividad, la sostenibilidad y el rendimiento económico de la explotación, mediante la identificación de todos aquellos problemas (peligros) que pueden potencialmente poner en riesgo la productividad (Banhazi and Black 2009).

El concepto HACCP surgió en los años 60 en Estados Unidos, con la colaboración de la empresa Pillsbury, el Ejército de los EEUU y la NASA, con la intención de desarrollar un sistema que garantizara el alimento seguro para los astronautas del programa espacial. Pillsbury introdujo este concepto al considerarlo el de mayores garantías en cuanto a seguridad alimentaria, al mismo tiempo que reducía la dependencia en inspecciones de producto terminado. Este concepto se centraba en los problemas que potencialmente podrían aparecer en cada fase del proceso, así como las causas posibles y su efecto más probable en el producto antes de aplicar mecanismos de control efectivos. HACCP enfatiza el control del proceso a lo largo de toda la cadena de producción mediante el uso de operadores y/o técnicas de monitoreo continuo en puntos críticos de control. En los años 80, empresas alimentarias importantes ya habían adoptado el sistema HACCP y, hoy en día, las agencias de control alimentario están imponiendo a la industria el uso de sistemas basados en HACCP para garantizar la seguridad alimentaria (FAO 1998; FAO 2001; Banhazi and Black 2009).

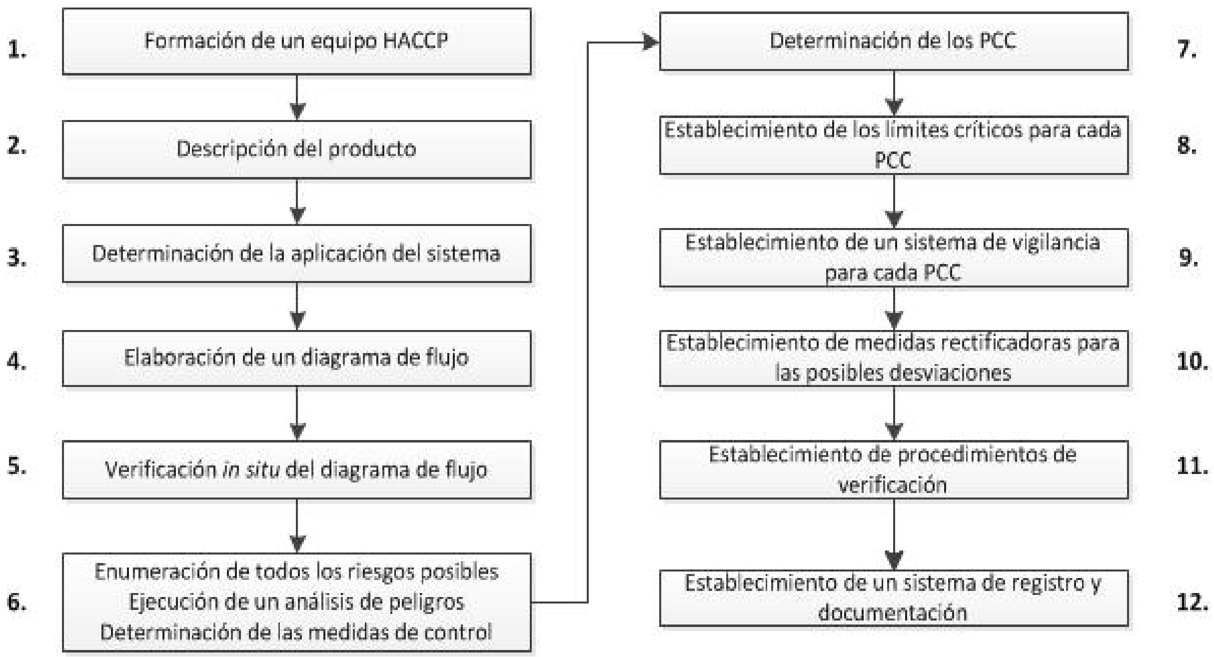

Figura 2. Aplicación lógica del sistema HACCP

El sistema HACCP consta de siete principios. Sin embargo, para aplicar este sistema se recomienda seguir doce pasos (Figura 2), según las directrices establecidas por la Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO 2001).

1. *Establecer el equipo HACCP*. El primer paso consiste en la creación del equipo humano encargado de desarrollar y llevar a cabo el plan HACCP.
2. *Descripción del producto*. El segundo paso consiste en describir el producto y sus parámetros clave.
3. *Identificar el uso esperado.* Describir el uso que se le va a dar al producto.
4. *Creación del diagrama de flujo*. El equipo HACCP debe construir un diagrama de flujo del proceso, cubriendo todas las fases de la operación.
5. *Confirmación del diagrama de flujo*. El diagrama de flujo creado en el paso anterior debe ser evaluado y confirmado con el proceso real y se perfeccionará donde sea necesario.
6. PRINCIPIO NÚMERO 1. *Enumeración de todos los posibles riesgos relacionados con cada fase, ejecución de un análisis de peligros y estudio de las medidas para controlar los peligros identificados.*

   El equipo de HACCP deberá enumerar todos los peligros que puede razonablemente preverse que se producirán en cada fase. Luego, el equipo de HACCP deberá llevar a cabo un análisis de peligros para identificar, en relación con el plan de HACCP, cuáles son los peligros cuya eliminación o reducción a niveles aceptables resulta indispensable.

   El equipo tendrá entonces que determinar qué medidas de control, si las hay, pueden aplicarse en relación con cada peligro. Puede que sea necesario aplicar más de una medida para controlar un peligro o peligros específicos, y que con una determinada medida se pueda controlar más de un peligro.
7. PRINCIPIO NÚMERO 2. *Determinación de los puntos críticos de control (PCC).*

   Dónde, dentro del proceso productivo, se encuentran los peligros identificados. Es posible que haya más de un PCC al que se aplican medidas de control para hacer frente a un peligro específico. La determinación de un PCC en el sistema de HACCP se puede facilitar con la aplicación de una secuencia de decisiones en el que se indique un enfoque de razonamiento lógico.

   Si se identifica un peligro en una fase en la que el control es necesario para mantener la inocuidad, y no existe ninguna medida de control que pueda adoptarse en esa fase o en cualquier otra, el proceso deberá modificarse en esa fase, o en cualquier fase anterior o posterior, para incluir una medida de control.
8. PRINCIPIO NÚMERO 3. *Establecimiento de límites críticos para cada PCC.*

   Para cada punto crítico de control, deberán especificarse y validarse, si es posible, límites críticos. Estos se definen como aquellos valores por encima y/o por debajo de los cuales el proceso no está bajo control. Entre los criterios aplicados suelen figurar las mediciones de temperatura, tiempo, nivel de humedad, pH, etc.
9. PRINCIPIO NÚMERO 4. *Establecimiento de un sistema de vigilancia para cada PCC.*

   La vigilancia es la medición u observación programadas de un PCC en relación con sus límites críticos. Mediante los procedimientos de vigilancia deberá poderse detectar una pérdida de control en el PCC. Además, lo ideal es que la vigilancia proporcione esta información a tiempo como para hacer correcciones que permitan asegurar el control del proceso para impedir que se infrinjan los límites críticos. En lo posible, los procesos deberán corregirse cuando los resultados de la vigilancia indiquen una tendencia a la pérdida de control en un PCC y las correcciones deberán efectuarse antes de que ocurra una desviación.

10. PRINCIPIO NÚMERO 5. *Establecimiento de medidas correctivas*.
    Con el fin de hacer frente a las desviaciones que puedan producirse, deberán formularse medidas correctivas específicas para cada PCC del sistema de HACCP. Estas medidas deberán asegurar que el PCC vuelva a estar controlado.
11. PRINCIPIO NÚMERO 6. *Establecimiento de procedimientos de comprobación.*
    Deberán establecerse procedimientos de comprobación para determinar si el sistema de HACCP funciona eficazmente. La frecuencia de las comprobaciones deberá ser suficiente para confirmar que el sistema de HACCP está funcionando correctamente.
12. PRINCIPIO NÚMERO 7. *Establecimiento de un sistema de documentación y registro.*
    Es fundamental contar con un sistema de registro eficaz y preciso. Por ejemplo, tener documentación relativa al análisis de peligros y a la determinación de los puntos críticos de control o las actividades de vigilancia de los PCC.

1.2.3 Caña de azúcar

Este Trabajo Final de Carrera ha basado su estudio en la caña de azúcar (*Saccharum officinarum*) por diversas razones. Este cultivo tiene un indudable valor para el sector agrícola, ya que Australia es el tercer mayor exportador del mundo de azúcar (Department of Agriculture 2012). Actualmente, la caña de azúcar en Australia es uno de los cultivos en los que está avanzando más rápidamente el uso de Agricultura de Precisión. La caída en el precio mundial del azúcar a finales de los años 90 frenó la adopción que pudo observarse en otros cultivos como los cereales, donde la expansión de tecnologías de precisión fue mucho más rápida (Bramley 2009). Por otro lado, el Centro Nacional de Ingeniería para la Agricultura (NCEA), donde se desarrolló este trabajo, es uno de los centros de investigación más activos de Queensland (Australia) especializados en el área de Agricultura de Precisión y más concretamente en su implementación en la caña de azúcar.

La caña de azúcar es una planta perteneciente a la familia de las gramíneas. El cultivo comercial de la caña de azúcar se propaga vegetativamente. Cada sección del tallo (aproximadamente 150-300 mm de largo) lleva al menos una yema. Los brotes primarios son seguidos por brotes secundarios y terciarios desde la porción basal de las primarias. Los troncos resultantes de la caña producen tallos 2 a 4 m de longitud y 25 a 50 mm de diámetro, en función de la variedad y de las condiciones de crecimiento. Los tallos se dividen por nodos. Las yemas son auxiliares y alternan de lado en cada sección. Las hojas se producen en cada nodo y las vainas de las hojas rodean el tallo (Reid 1981).

Para un buen crecimiento, la caña de azúcar necesita al menos 1.100 mm de lluvia (o riego) por año, un clima cálido y soleado, libre de heladas y suelos profundos, bien drenados. Un tiempo fresco inmediatamente antes de la cosecha frena el crecimiento de la planta y aumenta el contenido de azúcar en el tallo. La caña de azúcar es un cultivo versátil y crece satisfactoriamente en una amplia gama de suelos. La nivelación de la superficie y el drenaje subterráneo para eliminar el anegamiento son prácticas recomendadas (Bakker 1999).

En general, el ciclo del cultivo es de una plantación y tres rebrotes. En virtud de la biomasa producida por hectárea, provoca una gran extracción de nutrientes del suelo. Los factores que influyen en la cantidad de fertilizante aplicado, incluyen la clase de cultivo (planta o rebrotes), la humedad disponible, la fertilización previa y tipo de suelo. La respuesta a la fertilización con nitrógeno, fósforo y potasio en la fase de planta es diferente en la fase de rebrote. Por lo general, se aplica más fósforo a la fase de planta y más nitrógeno y potasio en la fase de rebrote (Bakker 1999).

Las secciones de caña de azúcar se plantan en fila, con una separación entre filas que van desde 1,4 hasta más de 2 m. La densidad de plantación es de cerca de 5 t/ha de secciones de caña. La plantadora de caña de azúcar utiliza secciones de caña cortadas en trozos pequeños por la cosechadora, la cual abre un surco, pasa las secciones a través de un spray o un baño que contiene una solución fungicida, se aplica fertilizante, cubre las secciones y compacta el suelo en una sola operación (Reid 1981).

La caña de azúcar es, dependiendo del clima, cosechada anualmente a nivel del suelo. Después, desde los brotes subterráneos vuelve a crecer una nueva planta (rebrote). En Queensland (Australia), se cosecha un promedio de tres rebrotes antes de que el rastrojo se incorpore a la tierra mediante labor y la tierra sea preparada para volver a plantar caña o un cultivo de descanso. Algunas parcelas de caña de azúcar pueden ser rebrotadas muchas más de tres veces, sobre todo si la cosecha se realiza de forma manual. La cosechadora primero corta las hojas superiores de la planta, después corta el tallo de la caña a la altura del suelo y ésta es cortada en pequeños trozos de 200 a 300 mm de largo. Estos trozos de caña son limpiados de material externo, sobre todo hojas y restos, mediante dos sistemas de extracción. La caña limpia se carga finalmente en un contenedor situado junto a la cosechadora (Reid 1981).

1.3 Objetivos

El presente Trabajo Final de Carrera tiene como objetivo general **el estudio de la teoría de Puntos Críticos de Control, como herramienta innovadora en la producción de caña de azúcar**.

A su vez, se desprenden cuatro objetivos específicos necesarios para la obtención del anterior, que son:

1. Identificar los peligros más importantes que limitan la producción de caña de azúcar.
2. Identificar qué factores de riesgo, dentro de cada problema, deben ser monitorizados para controlar el sistema.
3. Identificar en qué fase del proceso de producción se encuentran los peligros para la producción (Puntos Críticos de Control).
4. Averiguar qué frena a los agricultores ante la adopción de la Agricultura de Precisión como sistema de manejo.

1.4 Metodología empleada

El sistema HACCP tiene una amplia implementación en la industria alimentaria, por lo que nos encontramos con multitud de estudios basados en este sistema (Galan et al. 2003; Horchner et al. 2006; Hegelund and Sørensen 2007; Leifert et al. 2008). En la mayoría de los casos se siguen las directrices establecidas por la Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO), explicadas en la sección anterior. Este Trabajo Final de Carrera, al explorar un uso poco convencional de este sistema, estará basado en dichas directrices y combinará la metodología seguida en otros estudios para adaptarla a este nuevo enfoque. Sin embargo, se enfatizará el hecho de que ciertos peligros no pueden ser eliminados, reducidos a un nivel aceptable o completamente prevenidos. Por tanto, estará enfocado a reducir las posibilidades de introducción de peligros o riesgos.

Primer paso. El primer paso realizado fue la elaboración de un diagrama de flujo y su verificación (lo cual corresponde con los pasos 4 y 5 de la Figura 2 explicada en el apartado 1.2.2 Análisis de Riesgos y Puntos Críticos de Control (HACCP)). Esto será importante para ser capaces de localizar dónde, a lo largo del proceso de producción, se encuentran aquellos peligros que pueden potencialmente limitar la productividad

De los cinco primeros pasos de aplicación del sistema HACCP (relativos a la preparación previa a la aplicación de los Principios), los tres primeros (equipo HACCP, descripción del producto e identificar el uso esperado) no serán aplicados debido a que este Trabajo Final de Carrera tiene un carácter general. Sin embargo, se reconoce que estos tres pasos deberán formar parte del Plan HACCP cuando sea implementado en casos más específicos, por lo que tan solo serán descritos.

Para realizar el diagrama de flujo se utilizó el programa informático MS Visio 2010. De acuerdo con las directrices de la FAO, el diagrama de flujo debe ser evaluado y confirmado con el proceso real. Esto es válido para las industrias alimentarias pero, según se desprende de la guía práctica Campden BRI (2009), en la que estudian la implementación del sistema HACCP en el sector primario con el objetivo de asegurar la seguridad alimentaria, "la producción vegetal es una operación basada en el tiempo, en la que no es posible observar cada paso relevante en el proceso de producción en un único punto en el tiempo, puesto que puede llevar una ciclo completo". Debido a ello, se optó por revisar el diagrama de flujo con expertos en la materia y agricultores, tal y como se sugiere en el artículo presentado por Horchner and Pointon (2011).

Una vez terminada la fase de creación del diagrama de flujo, se procedió a aplicar los Principios que rigen el sistema HACCP (pasos 6 al 12 en la Figura 2).

Una vez más, las directrices de la FAO establecen la metodología a seguir. Pero de nuevo no se consideran las más adecuadas por su enfoque hacia la industria alimentaria. De acuerdo con la FAO, la enumeración de todos los posibles riesgos relacionados con cada fase (Principio 1) se debe llevar a cabo por un equipo multidisciplinario, la determinación de los puntos críticos de control (PCC) (Principio 2) se debe realizar por el equipo HACCP con la ayuda de una secuencia de decisiones (Figura 3) y el establecimiento de límites críticos para cada PCC (Principio 3) será de nuevo decidido por el equipo HACCP.

Según Campden BRI (2009), en el caso de pequeñas empresas en las que sea difícil o demasiado costoso tener un equipo HACCP, se recomienda que una persona represente el equipo HACCP y se acuda a consultores externos para las áreas de conocimiento necesarias. Además, Hegelund and Sørensen (2007) afirman que en aquellos casos en los que no hay suficiente información para realizar un análisis tradicional, se debe recurrir a paneles de expertos.

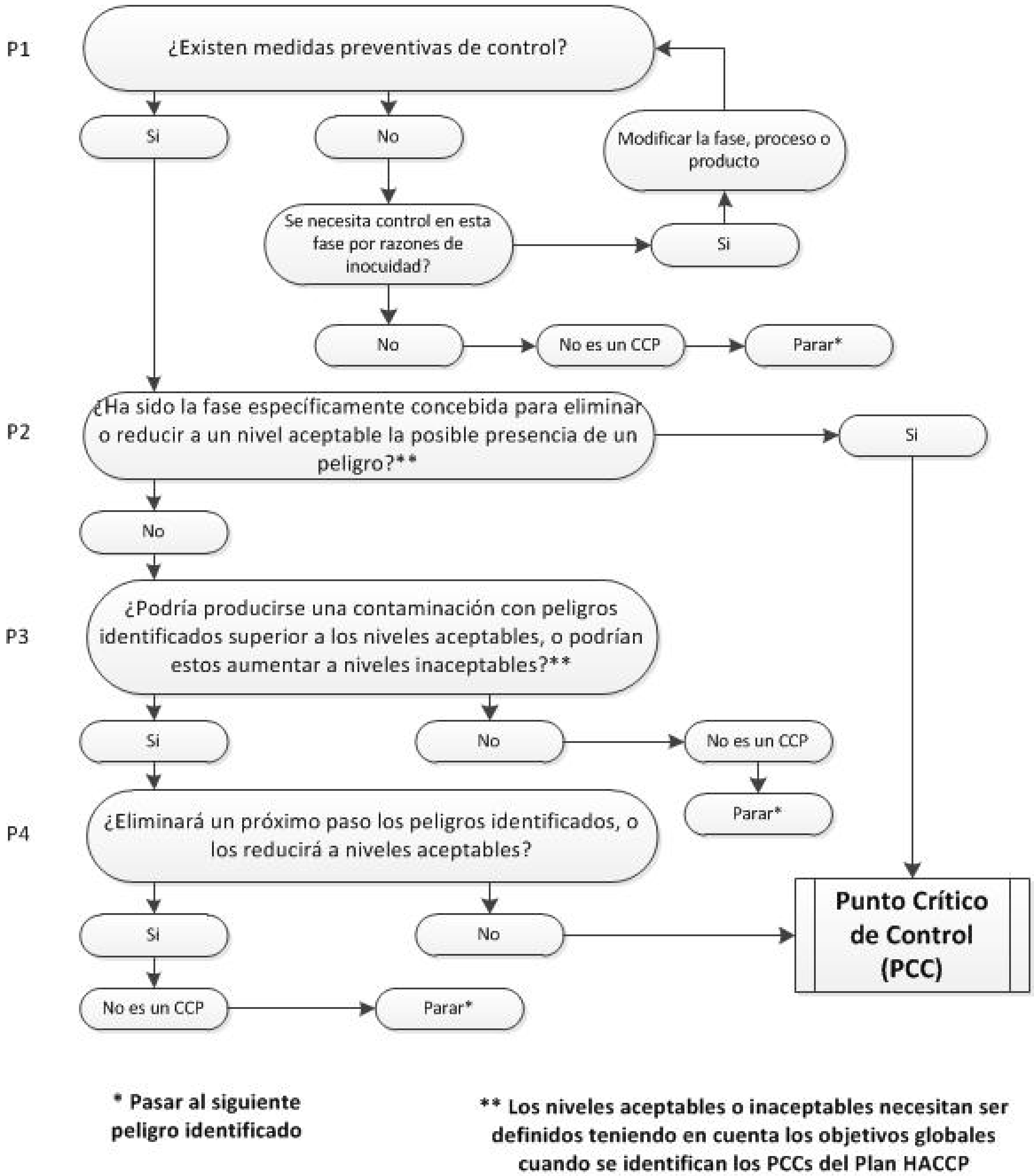

Figura 3. Secuencia de decisiones. Fuente: FAO.

Debido a que este Trabajo tiene un enfoque distinto al tradicional y no se conocen casos en la aplicación del sistema HACCP en producción vegetal, así como por la ausencia de un equipo HACCP tal y como es propuesto por la FAO, se siguió la metodología establecida por Hegelund and Sørensen (2007). En su estudio, en el que implementaban el sistema HACCP para mejorar la salud y el bienestar de los animales en la producción de huevos orgánicos, realizaron cuatro cuestionarios para completar los Principios 1, 2 y 3 (pasos 6,7 y 8 en la Figura 2).

Los tres primero cuestionarios resolverán el Principio 1 y el cuarto cuestionario los Principios 2 y 3.

Cuestionario 1. El primer cuestionario consta de dos listas independientes. La primera de ellas enumera 48 problemas que pueden poner en riesgo la producción de caña de azúcar, como por ejemplo la disponibilidad del agua, la presencia de plagas, etc. (Tabla 1) y la segunda lista enumera, por otro lado, nueve problemas que pueden influir en la adopción de sistemas de precisión por parte de los agricultores (Tabla 2). El objetivo de estas listas es, por un lado, identificar los problemas que, según el criterio de expertos, investigadores y agricultores, son más importantes atender para lograr un mayor rendimiento del cultivo y, por otro lado, los cuatro problemas que más desaniman a los agricultores a la hora de decantarse por tecnologías de precisión. Estas dos listas de problemas fueron realizadas mediante revisión bibliográfica y reuniones preliminares con algunos expertos y agricultores, con la intención de abarcar diferentes puntos de vista. Cada uno de los problemas señalados en ambas listas tenían que ser puntuados en una escala del 1 al 5 de acuerdo a criterios de severidad (cómo de grave es el problema) y frecuencia (cada cuánto tiempo ocurre el problema). Al obtener la mediana y el valor medio de todas las puntuaciones de severidad y frecuencia, se identifican los problemas más importantes y se utiliza el rango intercuartil (IQR), usado por Hegelund and Sørensen (2007) para cuantificar el nivel de consenso de las respuestas obtenidas, de tal manera que: IQR $\leq$ 0.5 alto nivel de consenso; 0.5 < IQR $\leq$ 1 consenso moderado; IQR > 1 sin consenso.

Tabla 1. Lista de problemas de producción a puntuar en el cuestionario 1

nr	*Problema*	*Severidad (1-5)*	*Frecuencia (1-5)*
1	pH del suelo		
2	Tipo de suelo (textura)		
3	Densidad aparente del suelo (compactación)		
4	Capacidad de Intercambio Catiónico del suelo		
5	Materia orgánica del suelo		
6	Erosión/degradación del suelo (eólica / hídrica)		
7	Contaminación del suelo (pesticidas/herbicidas/fertilizante)		
8	Salinidad del suelo		
9	Intoxicación de las plantas (pesticidas/herbicidas)		
10	Contaminación del medio ambiente		
11	Suelos Sulfatados Ácidos (SSA)		
12	Profundidad del suelo		
13	Plagas		
14	Enfermedades		
15	Malas hierbas		
16	Disponibilidad de agua		
17	Calidad del agua		
18	Sistema de riego		
19	Drenaje / encharcamiento		
20	Escorrentía / lavado / pérdida de nutrientes /		

	contaminación de acuíferos		
21	Topografía		
22	Fertilización/tipo de fertilización		
23	Fecha de la cosecha		
24	Cosecha en verde / quemado		
25	Selección de la variedad		
26	Rotación del cultivo		
27	Número de retoño		
28	Plantación (densidad, costes)		
29	Lavado de contaminantes		
30	Distancia a ríos / mar / humedales / bosques		
31	Presencia de especies amenazadas		
32	Áreas protegidas		
33	Ruido		
34	Contaminación ambiental		
35	Gestión de residuos		
36	Lluvia		
37	Temperatura		
38	Granizo		
39	Radiación solar		
40	Maquinaria adecuada		
41	Barbecho		
42	Tecnologías		
43	Herramientas del gerente		
44	Conocimiento del gerente		
45	Pérdidas en la cosecha (extractor, corte, velocidad de avance, …)		
46	Costes asociados a la cosecha		
47	Rendimiento de las aplicaciones químicas		
48	Desastres naturales (ciclones, lluvias torrenciales,sequía)		

Tabla 2. Lista de problemas de adopción de tecnologías de precisión a puntuar en el cuestionario 1

nr	*Problema*	*Severidad (1-5)*	*Frecuencia (1-5)*
1	Obsolescencia		
2	Compatibilidad		
3	Conocimiento del potencial del equipo		
4	Conocimiento de qué hacer con la información obtenida		
5	Idoneidad del equipo (específico para el cultivo)		
6	Servicio técnico		
7	Coste		
8	Mapas de rendimiento		
9	Beneficio derivado del uso del equipo		

Cuestionario 2. El segundo cuestionario fue creado a partir de los resultados del primer cuestionario. Siguiendo el método descrito anteriormente, se hizo una lista seleccionando los diez problemas más importantes que limitan el rendimiento de la caña de azúcar y otra lista con los cuatro problemas más importantes a la hora de adquirir tecnologías de precisión por parte de los agricultores. Este cuestionario fue enviado a nueve personas, las cuales sugirieron factores de riesgo para cada uno de los problemas seleccionados.

Cuestionario 3. El tercer cuestionario fue creado a partir de los resultados obtenidos en el segundo cuestionario. Se creó una lista similar a la del cuestionario número 1, en la que se enumeraban los factores de riesgo sugeridos por cada problema limitando el rendimiento de la caña de azúcar, así como los factores de riesgo de los problemas más importantes a la hora de adquirir tecnologías de precisión por parte de los agricultores. Estos factores de riesgo fueron puntuados de la misma manera que en el cuestionario número 1, esto es, en una escala del 1 al 5 de acuerdo a la severidad y la frecuencia de ocurrencia. El fin de este cuestionario era identificar los factores de riesgo más determinantes en los que se debería enfocar el plan HACCP, lo que equivale al Principio número 1: enumeración de los posibles riesgos. Debido a una cantidad de factores de riesgo por cada problema mayor del esperado y para asegurar un cuestionario de un tamaño aceptable, se seleccionaron seis problemas, contabilizando noventa y dos factores de riesgo en total para ser puntuados. Se recogieron cinco respuestas.

Cuestionario 4. El último cuestionario fue preparado nuevamente a partir de los resultados obtenidos en el cuestionario 3. Se seleccionaron los diez factores de riesgo con mayores puntuaciones de acuerdo a la mediana y al valor medio. El objetivo de este último cuestionario es completar los Principios 2 y 3: la determinación de los puntos críticos de control y el establecimiento de límites críticos para cada PCC, respectivamente. Se adjuntó el diagrama de flujo corregido del proceso junto con el cuestionario para ayudar en la identificación de los puntos críticos del proceso. También se debían sugerir límites críticos para cada factor de riesgo.

1.5 Resultados y discusión

El diagrama de flujo confirmado para el proceso de producción de caña de azúcar puede verse en la Figura 4. El diagrama de flujo fue mejorado y confirmado por expertos y agricultores para representar, con el suficiente nivel de detalle, las fases más importantes del proceso de producción, desde la preparación del suelo hasta el transporte de la caña a la refinería.

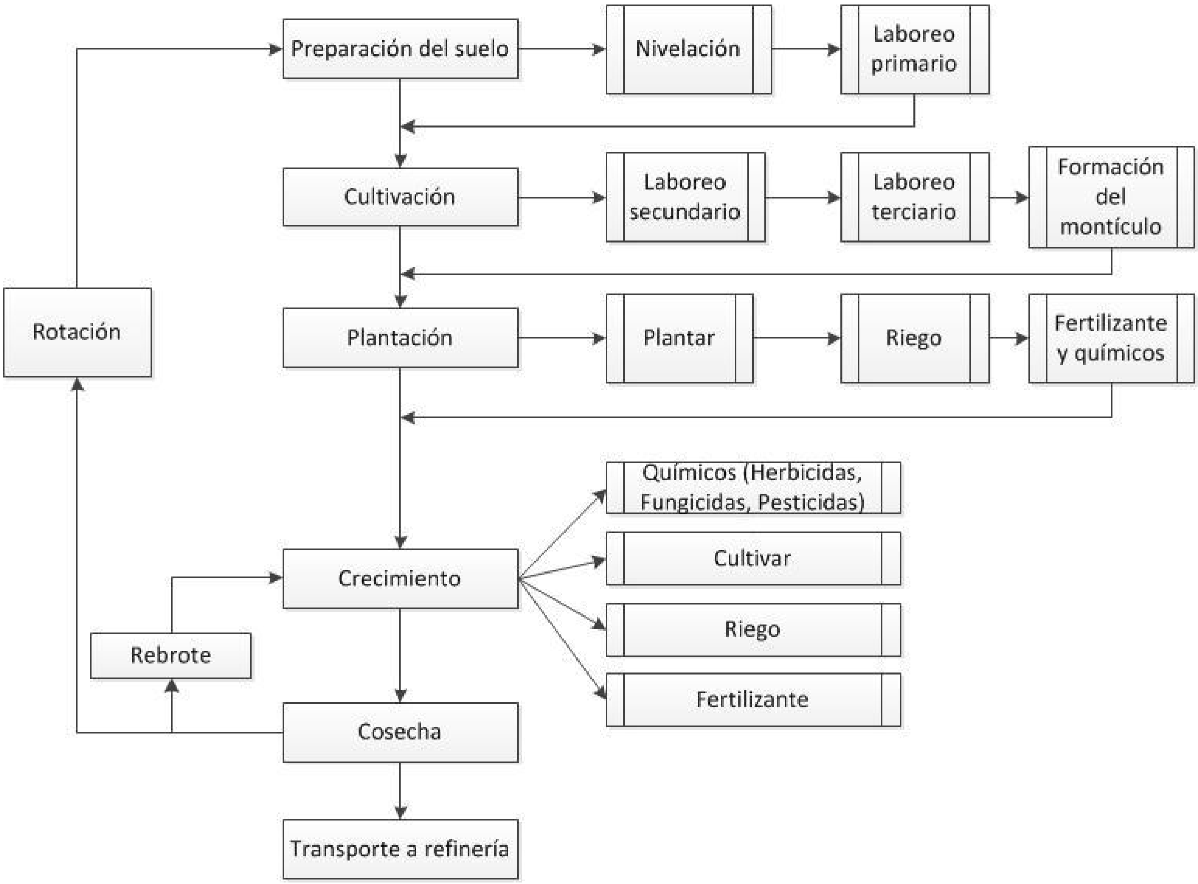

Figura 4. Diagrama de flujo del proceso de producción de caña de azúcar

Cuestionario 1. Se recibieron nueve respuestas para el primer cuestionario. Estas respuestas hacen referencia a localizaciones que se encuentran a 1.500 kilómetros de distancia, con lo que se cubrieron climas y suelos totalmente distintos.

Con los resultados obtenidos de este primer cuestionario, se seleccionaron los diez problemas más importantes (Tabla 3): pérdidas durante la cosecha, costes de la cosecha, selección de la variedad, lluvia, compactación, plagas, nivel de conocimiento del gerente, malas hierbas, enfermedades y fecha de la cosecha. Los índices IQR mostraron un buen consenso general, habiendo cuatro casos sin consenso en la severidad de los problemas (IQR>1) y tan sólo un caso sin consenso en cuanto a la frecuencia. El problema con mayor puntuación fue "pérdidas en la cosecha", el cual muestra un consenso alto tanto en severidad (0,25) como en frecuencia (0,25), por lo que se puede decir que es un problema que afecta, en general, a todas las personas involucradas en la producción de caña de azúcar, sin perjuicio de su localización.

En cuanto a los problemas influyentes en la toma de decisión para la adopción de tecnologías de precisión, los cuatro más importantes, con sus puntuaciones, se pueden ver en la Tabla 4. Estos son

(i) la compatibilidad entre equipos, (ii) el conocimiento de saber qué hacer con la respuesta obtenida con la tecnología, (iii) el coste y (iv) el beneficio obtenido con la tecnología, ya sea en forma de mayor rendimiento, disminución de costes, etc. En todos los casos el nivel de consenso se sitúa entre moderado y alto.

Tabla 3. Resultados del primer cuestionario para problemas de productividad

		Severidad				Frecuencia			
	PROBLEMAS	*n*	*Mediana*	*Media*	*IQR*	*n*	*Mediana*	*Media*	*IQR*
1	Pérdidas en la cosecha	8	4	4.25	0.25	8	4	4.13	0.25
2	Costes de la cosecha	8	4	4.13	1.25	8	4	4.25	1
3	Selección de la variedad	8	4	3.88	1.25	8	4	3.88	1.25
4	Lluvia	9	4	3.78	1	9	4	3.67	1
5	Compactación del suelo	9	4	3.67	1	9	4	3.67	1
6	Plagas	9	4	3.44	1	9	4	3.78	0
7	Conocimientos del gerente	8	4	3.88	1.25	8	3.5	3.50	1
8	Malas hierbas	9	4	3.44	1	9	4	3.33	1
9	Enfermedades	9	4	3.22	2	9	4	3.44	1
10	Fecha de la cosecha	8	4	3.38	1	8	3.5	3.38	1

Tabla 4. Resultados del primer cuestionario para problemas en la adopción de tecnologías de precisión

		Severidad				Frecuencia			
	PROBLEMAS	*n*	*Mediana*	*Media*	*IQR*	*n*	*Mediana*	*Media*	*IQR*
1	Compatibilidad	9	5	4.33	1	9	4	3.67	0
2	Qué hacer con la respuesta obtenida	9	4	3.89	0	9	4	3.67	1
3	Coste de adquisición	8	4	4	0.5	8	4	3.63	1
4	Beneficios obtenidos (reducción costes, aumento rendimiento,…)	7	4	4	1	7	4	4	0

Cuestionario 2. El segundo cuestionario fue creado a partir de los resultados anteriores. Se listaron los diez problemas con mayor puntuación en productividad y los cuatro problemas con mayor puntuación en adopción de tecnologías de precisión. Se recibieron nueve respuestas con un total de 353 factores de riesgo, 273 de los cuales dedicados a los problemas de productividad y los 80 restantes a los problemas de adopción. Esto supone 39,2 factores de riesgo de media por cada respuesta. Se editaron las sugerencias y eliminaron los factores repetidos o de problemas que no pasaron al siguiente cuestionario (Hegelund and Sørensen 2007), por lo que la cifra se redujo a 123 factores de riesgo. 92 factores atendiendo seis problemas de productividad y 31 factores para cuatro problemas de adopción.

Cuestionario 3. Los 92 factores de riesgo para problemas de productividad y los 31 factores de problemas de adopción de tecnologías de precisión fueron puntuados por el panel de expertos en el tercer cuestionario. Se obtuvieron cinco respuestas para calcular los factores con mayor puntuación.

Entre los factores de riesgo para la productividad, 65 de los 92 factores mostraban un nivel de consenso moderado o alto para la severidad y 62 para la frecuencia. Entre los factores de adopción de tecnologías, 24 de los 31 mostraban consenso moderado o alto para la severidad y 25 para la frecuencia. Estos resultados indican que la mayoría de los factores de riesgo son percibidos de manera similar (ya sea tanto por importantes como por triviales) a pesar de las diferentes perspectivas. Sin embargo, aunque pocos, se dan algunos casos de respuestas totalmente opuestas, lo que puede indicar que la manera en que se percibe el factor de riesgo puede ser determinante a la hora de darle un valor subjetivo a la severidad o a la frecuencia, que se percibe de forma incorrecta o puede incluso sugerir que la forma en la que se presentan los cuestionarios afecta a cómo se perciben ciertos riesgos, dando lugar a una valoración que no se corresponde con la realidad (Troy Jensen, responsable del área de PA, NCEA, comunicación personal). No obstante, el buen consenso general parece indicar que en aquellos casos en los que no se cumplen los criterios de consenso, puede ser debido a las diferencias que existen entre las distintas áreas que cubre el estudio y/o diferencias en el punto de vista entre expertos y agricultores.

Los resultados de los factores de riesgo con mayor puntuación pueden verse en la Tabla 5 y la Tabla 6. Estos se reparten en dos categorías de problemas en cada caso: cosecha y compactación en el caso de la productividad y beneficios y coste en el lado de la adopción de estas tecnologías. Esto demuestra que la opinión de los expertos consultados está fuertemente polarizada en áreas concretas. Sin embargo, hay que destacar que, sorprendentemente, el riego o los recursos hídricos no fueran señalados como peligros prioritarios para la producción de caña de azúcar, ya que es comúnmente aceptado como uno de los factores más limitantes de la producción (Craig Baillie, Director de NCEA, comunicación personal). Esto puede deberse a lo comentado anteriormente, puesto que al ser un factor limitante tan obvio, es posible que ni siquiera fuera percibido como tal en este estudio, al existir ya un manejo que se encargue de controlar este problema, aunque no sea de forma óptima. Esto obliga a tomar los resultados obtenidos con cautela y sugiere que próximos estudios más rigurosos en parcelas, deberían ser llevados a cabo por un equipo multidisciplinario de expertos en las diferentes áreas de la producción más críticas, en las que se juzgue en cada caso la importancia económica de los distintos problemas considerados.

El factor de riesgo con mayor puntuación, de acuerdo a los cuestionarios y con un consenso moderado, como se observa en la Tabla 5, es “azúcar perdido en el campo” durante la cosecha. Esto significa que dentro de la amplia perspectiva que abarcan estos cuestionarios, tanto expertos como agricultores de distintas áreas coinciden en señalar este factor de riesgo como el que más significativamente afecta al rendimiento real del cultivo.

Tabla 5. Diez factores de riesgo más importantes en la producción de caña de azúcar

			Severidad				Frecuencia			
nr	*Problema*	*Factores de riesgo*	*n*	*Mediana*	*Media*	*IQR*	*n*	*Mediana*	*Media*	*IQR*
1	Cosecha	Azúcar perdido en campo	5	5	4.6	1	5	4	4.2	1
2		Diseño cosechadora	5	4	3.6	2	5	5	3.8	2
3		Daño de los tallos	5	4	4.2	0	5	4	4.2	1
4		Falta de reconocimiento de la cadena de valor	5	4	4	2	5	4	4	1
5		Ineficiencia	5	4	3.8	1	5	4	4	2
6		Experiencia, conocimiento, entrenamiento del conductor	5	4	3.8	2	5	4	3.8	1
7	Compactación	Reducción de producción	5	4	4.4	1	5	4	4	1
8		Tráfico Controlado	5	4	4.2	0	5	4	4	0
9		Maquinaria conducida sobre los tallos	5	4	4.4	1	5	4	3.8	0
10		Peso de la maquinaria	5	4	4	0	5	4	4	0

Tabla 6. Cuatro problemas más importantes frenando la adopción de tecnologías de precisión

			Severidad				Frecuencia			
nr	*Problema*	*Factores de riesgo*	*n*	*Mediana*	*Media*	*IQR*	*n*	*Mediana*	*Media*	*IQR*
1	Beneficios obtenidos	Regulaciones gubernamentales	5	5	4	2	5	5	4.2	1
2		Percepción del agricultor	5	4	4.2	1	5	4	4	2
3	Coste de adquisición	Tamaño de la explotación para hacer frente a costes	5	5	4.4	1	5	4	3.8	0
4		Incertidumbre en la recuperación de la inversión	5	4	4	0	5	4	4	0

El último cuestionario, el cuestionario número cuatro, fue recibido por tres personas de la misma región (Herbert, Queensland Norte). Todos los cuestionarios fueron realizados por expertos o investigadores. En ellos, se apuntan con más detalle las causas que influyen en los diez factores de riesgo para la productividad. A grandes rasgos, pocos siguieron las instrucciones de localizar en el diagrama de flujo del proceso los Puntos Críticos de Control aunque, como era de esperar, estos se concentran principalmente en la fase de la cosecha. Por esto, hubo una cantidad de Puntos Críticos de Control no aplicables al ámbito de estudio mayor de la esperada, como por ejemplo el diseño de la cosechadora. Sin embargo, para el factor de riesgo que ocupa esta parte del estudio, "azúcar perdido en el campo", sólo se hizo referencia a la fase de cosecha, como era de esperar. Gran parte de los límites críticos sugeridos eran imprecisos o no ofrecían garantías de resolver el problema a tiempo, como por ejemplo "los responsables no tienen conocimientos de los problemas", "planificación deficiente", "velocidad lenta del tractor" o "rebrotes de mala calidad". En este último ejemplo, para "daños en el tallo" por maquinaria, es claramente un efecto de dichos daños el observar rebrotes de mala calidad y es demasiado tarde para evitar que suceda. Las sugerencias de límites críticos poco concretos es algo habitual en los cuestionarios (Hegelund and Sørensen 2007). Otros valores sugeridos que serían adecuados para controlar que esto no ocurra sería no sobrepasar los 7 km/h durante la cosecha y no conducir sobre las plantas recién cortadas.

En general, no se recibieron suficientes cuestionarios como para valorar las diferencias entre los límites críticos sugeridos. No obstante, en esta fase de desarrollo del proyecto no supone un gran inconveniente puesto que tiene un carácter demostrativo. Además, para establecer límites críticos en una explotación de caña de azúcar real, se debería atender a la bibliografía específica a su localización y a la opinión de expertos con un amplio conocimiento de la zona. En muchos casos, sin embargo, será necesario realizar una investigación previa a la implementación del sistema HACCP con el objeto de conocer los valores óptimos para cada factor de riesgo. El Plan HACCP debe basarse en acciones preventivas que incrementen las posibilidades de éxito y disminuyan las posibilidades de introducción de peligros que limiten la productividad y el rendimiento económico del cultivo (Banhazi and Black 2009). Cuando se detecte un factor de riesgo que no esté operando en condiciones óptimas, debe ser devuelto al nivel adecuado automáticamente o manualmente mediante el uso de medidas correctoras.

1.6 Conclusión

Este Trabajo Final de Carrera trata de establecer las bases para posteriores estudios más profundos y específicos en la aplicación del sistema HACCP en explotaciones agrarias; primero en cultivos de caña de azúcar y posteriormente en otro tipo de cultivos de interés.

1.1. Los problemas de producción más importantes a lo largo del proceso productivo de caña de azúcar, por orden de importancia, fueron los siguientes:

1) Pérdidas en la cosecha
2) Costes asociados a la cosecha
3) Selección de la variedad
4) Lluvia
5) Densidad aparente del suelo (compactación)
6) Plagas
7) Nivel de conocimiento del gerente de la explotación
8) Malas hierbas
9) Enfermedades
10) Fecha de la cosecha

2.1. Los factores de riesgo que deberían ser vigilados y controlados exhaustivamente pertenecen al ámbito de la cosecha y la compactación del suelo, y son los siguientes:

- Cosecha:
    - Pérdida de azúcar en el campo
    - Diseño de la cosechadora
    - Daño del tallo
    - Falta de reconocimiento de la cadena de valor que supone la cosecha
    - Ineficiencia
    - Experiencia, conocimientos, entrenamiento del conductor
- Compactación:
    - Reducción de la producción
    - Tráfico controlado
    - Maquinaria conducida sobre los tallos
    - Peso de la maquinaria

2.2. Factores identificados en este estudio, como el diseño de maquinaria, no pueden ser controlados en el proceso de producción de la caña de azúcar, por lo que el plan HACCP no puede aplicarse en estos casos.

2.3. La disponibilidad de agua, “lluvia”, fue el cuarto problema más importante. Sin embargo, no tuvo mayor relevancia en cuanto a sus factores de riesgo. El método elegido para este estudio (cuestionarios) ha sido parcialmente eficaz para identificar los factores de riesgo más relevantes.

3. Existe un punto crítico de control, “cosecha”, en el que se debe hacer frente a la mayor parte de los problemas y factores de riesgo identificados.

4. Los agricultores pueden mostrar reticencias a la hora de adoptar sistemas de precisión en sus explotaciones principalmente debido a:
   - El beneficio derivado del uso de éstas tecnologías, que a su vez dependen de regulaciones gubernamentales (subvenciones, etc.) y de la percepción que tiene el agricultor de los beneficios potenciales.
   - El coste asociado a la adquisición de los equipos, principalmente influido por un tamaño de la explotación adecuado para hacer frente a los gastos así como por la incertidumbre de recuperar la inversión.

Futuros estudios: los resultados obtenidos en este estudio ofrecen un buen punto de partida para la siguiente fase del proyecto de implementación satisfactoria del sistema HACCP en cultivos de caña de azúcar bajo Agricultura de Precisión. Mediante el uso de cuestionarios, con la ayuda de expertos, investigadores y agricultores de una extensa zona en el Estado de Queensland (Australia), han podido ser identificados diversos problemas que limitan la productividad y el rendimiento económico de las explotaciones. Sin embargo, no han sido identificados satisfactoriamente con este método, problemas importantes como el riego o la disponibilidad del agua entre los diez problemas más importantes durante el primer cuestionario, a pesar de que la lluvia ha sido el problema número cuatro en orden de importancia y por extensión podría incluirse en el área de riego. Las diferencias geográficas y por tanto, las características de las explotaciones estudiadas así como las distintas perspectivas tenidas en cuenta en los cuestionarios, puede haber influido en este inesperado resultado. En posteriores Análisis de Riesgos y Puntos Críticos de Control que se llevarán a cabo en explotaciones concretas, sería aconsejable justificar empíricamente, por su impacto en la economía de la caña de azúcar, los riesgos en los que se va a concentrar el Plan HACCP.

2. INTRODUCTION

2.1 Precision Agriculture

The agricultural productivity of land is highly variable (Bramley 2009). When agriculture was poorly developed, this variability could be handled manually. However, the mechanisation of farms allowed to crop increasingly bigger fields, which had to be managed uniformly for practical reasons. So far, although this variability was known since the early 20th century (Fairfield Smith 1938), it has been considered an uncontrollable variation and treated as noise in the agricultural system (Cook and Bramley 1998). This implies a management of the farms that assumes that the field is homogeneous and decisions are made according to average values (yield, soil properties, fertilisation needs, etc.). Nevertheless, the deviation from that average value can be substantial.

The recent availability of some key enabling technologies has allowed this spatial variation to be considered and monitored in order to apply the most suitable treatment in each situation. Global positioning systems (GPS), geographical information systems (GIS), crop yield monitors, variable rate application (VRA) and remote sensing are the most important (Swinton and Lowenberg-DeBoer 2001; Bramley 2009).

Since this is possible, awareness is increasing worldwide that crop management practices need to be location specific in order to produce more food with higher profitability and to reduce risks to the environment (Buresh 2010).

In Precision Agriculture (PA), the crop is treated as a spatially variable entity. In recognising substantial within-paddock variation, PA also attempts to explain and predict the likelihood of response to controllable inputs as it varies over space (Cook and Bramley 1998).

Precision Agriculture is therefore a management system which is applicable to any controllable input. The general objective is to increase the likelihood of benefit and decrease the likelihood of risk (Cook and Bramley 1998). It leads not only to a more responsible farming through the efficient use of resources but also to significant economic benefits in some cases.

In Australia, the major crop under PA is dryland wheat (Bramley 2009). In a recent study on the use of variable rate technology (VRT) in Australian grain growers, benefits ranging between $7-$22/ha were identified. Lowenberg-DeBoer (2003) concluded, for the same technology, that will be break-even at best for crops such as corn and is likely to be profitable for higher value crops, as it is the case with sugarcane in Australia.

2.2 Hazard Analysis and Critical Control Point (HACCP)

Hazard Analysis and Critical Control Point (HACCP) is defined as a science based systematic system that identifies, in a process, hazards and measures for their control. The HACCP concept was pioneered in the 1960s by the Pillsbury Company, the United States Army and the United States National Aeronautics and Space Administration (NASA) as a collaborative development for the production of safe foods for the United States space programme. NASA wanted a "zero defects" programme to guarantee the safety of the foods that astronauts would consume in space. Pillsbury therefore introduced and adopted HACCP as the system that could provide the greatest safety while reducing dependence on end-product inspection and testing. It was based on the engineering system Failure, Mode and EffectAnalysis (FMEA) which looked at what could potentially go wrong at each stage in the operation along with possible causes and the likely effect, before applying effective control mechanisms. HACCP emphasized control of the process as far upstream in the processing system as possible by utilizing operator control and/or continuous monitoring techniques at critical control points. Pillsbury presented the HACCP concept publicly at a conference for food protection in 1971. The use of HACCP principles in the promulgation of regulations for low-acid canned food was completed in 1974 by the United States Food and Drug Administration (FDA). In the early 1980s, the HACCP approach was adopted by other major food companies. It is increasingly being promoted throughout the world and, in some countries, food control agencies are mandating the food industry to use HACCP based systems to assure food safety (FAO 1998; FAO 2001).

On agriculture, some approaches have been made in order to extend the food safety chain from the industries to the primary production (Hegelund and Sørensen 2007; Leifert et al. 2008; Horchner and Pointon 2011). It has been recognised that the system is applicable to any agricultural process including safety in the primary production (Campden BRI 2009). Banhazi and Black (2009) showed that a strict application of the HACCP principles would increase profitability and sustainability of livestock farms besides the abovementioned safety and food quality. Therefore, it is expected that this system will also increase the profitability and sustainability in agriculture. However, as yet, very few instances have been cited on the application of this system in primary production, especially in cropping enterprises.

2.2.1 PRINCIPLES OF THE HACCP SYSTEM

HACCP is a system that identifies specific hazards and specifies measures for their controls. According to (FAO 2001), the system consists on the following seven principles:

- PRINCIPLE 1: Conduct a hazard analysis.
- PRINCIPLE 2: Determine the Critical Control Points (CCPs).
- PRINCIPLE 3: Establish critical limit(s).
- PRINCIPLE 4: Establish a system to monitor control of the CCP.
- PRINCIPLE 5: Establish the corrective action to be taken when monitoring indicates that a particular CCP is not under control.
- PRINCIPLE 6: Establish procedures for verification to confirm that the HACCP system is working effectively.
- PRINCIPLE 7: Establish documentation concerning all procedures and records appropriate to these principles and their application.

2.2.2 APPLICATION OF HACCP PRINCIPLES

According to (FAO 2001), the application of HACCP should be done following 12 steps (Figure 1). Two parts can be distinguished: planning stages to enable hazard analysis (steps 1-5) and establishing the HACCP plan (steps 6-12, HACCP principles).

Step 1. Assemble HACCP team

Ensure that the appropriate knowledge and expertise is available for the development of an effective HACCP plan. This is best obtained by assembling a multi-disciplinary team. The scope of the HACCP plan should be identified. The scope includes process details such as the location where the sugarcane is produced or the start and end point of the study.

Step 2. Describe product

Describe the product and key parameters that influence product safety and quality.

Step 3. Identify intended use

The intended use should be based on expected uses of the product by the end user.

Step 4. Construct flow diagram

Flow diagram construction by the HACCP team, covering all the steps in the operation. It should provide sufficient technical detail for the study to proceed.

Step 5. On-site confirmation of flow diagram

Confirm the processing operation against the flow diagram and amend it where appropriate.

Step 6. List all potential hazards associated with each step, conduct a hazard analysis, and consider any measures to control identified hazards (PRINCIPLE 1)

List all the hazards that may be expected to occur at each step. Next, conduct a hazard analysis to identify which hazards are of such a nature that their elimination or reduction to acceptable levels is essential.

In conducting the hazard analysis, wherever possible the following should be included:

- The likely occurrence of hazards and severity of their adverse health effects
- The qualitative and/or quantitative evaluation of the presence of hazards

Step 7. Determine Critical Control Points (PRINCIPLE 2)

The determination of a CCP in the HACCP system should be done using professional judgment and could be facilitated by the application of a decision tree (Figure 2), which indicates a logical reasoning approach and should be used for guidance when determining CCPs.

Step 8. Establish critical limits for each CCP (PRINCIPLE 3)

Critical limits must be specified and validated for each CCP.

Step 9. Establish a monitoring system for each CCP (PRINCIPLE 4)

Monitoring is the scheduled measurement or observation of a CCP relative to its critical limits. It should detect loss of control over a CCP or a trend towards a loss of control, so adjustments can be made before the limits are trespassed.

Step 10. Establish corrective actions (PRINCIPLE 5)

Specific corrective actions should be developed for each CCP in case deviation occurs. They must ensure that the CCP has brought under control.

Step 11. Establish verification procedures (PRINCIPLE 6)

Establish verification procedures to determine if the HACCP system is working correctly. The efficient frequency of verification should be determined.

Step 12. Establish Documentation and Record Keeping (PRINCIPLE 7)

It is necessary an efficient and accurate record keeping of the HACCP system. It includes, for instance, documentation of hazard analysis and CCP determination or recording of CCP monitoring activities, deviations and associated corrective actions.

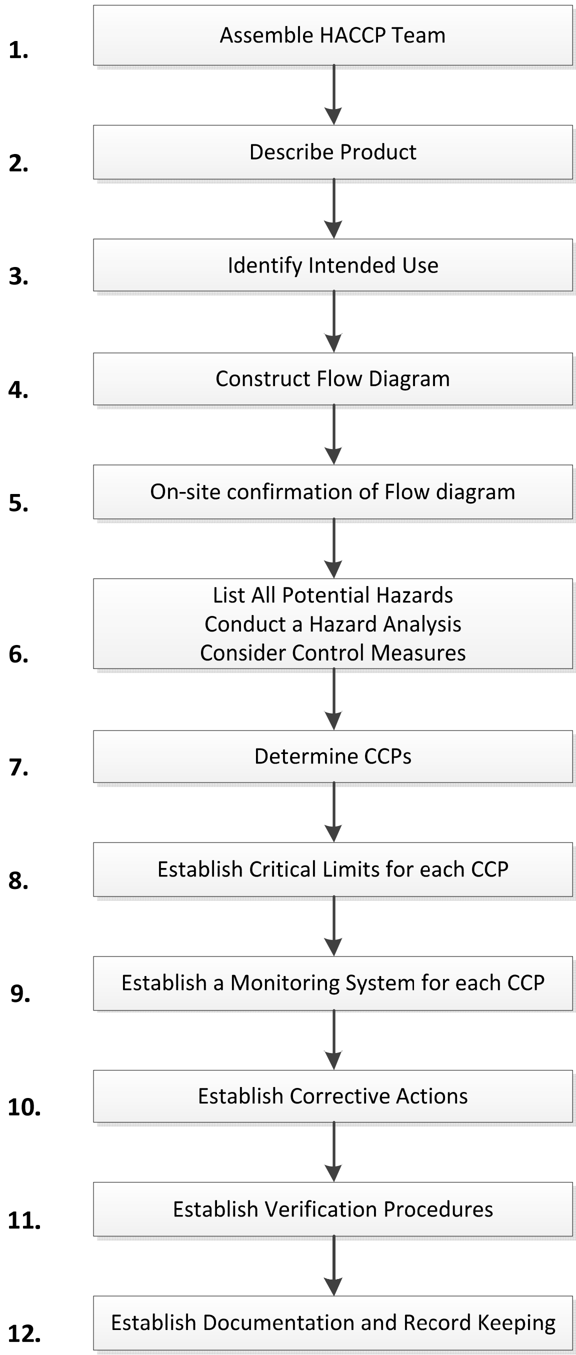

Figure 1. Logic sequence of HACCP application (FAO 2001)

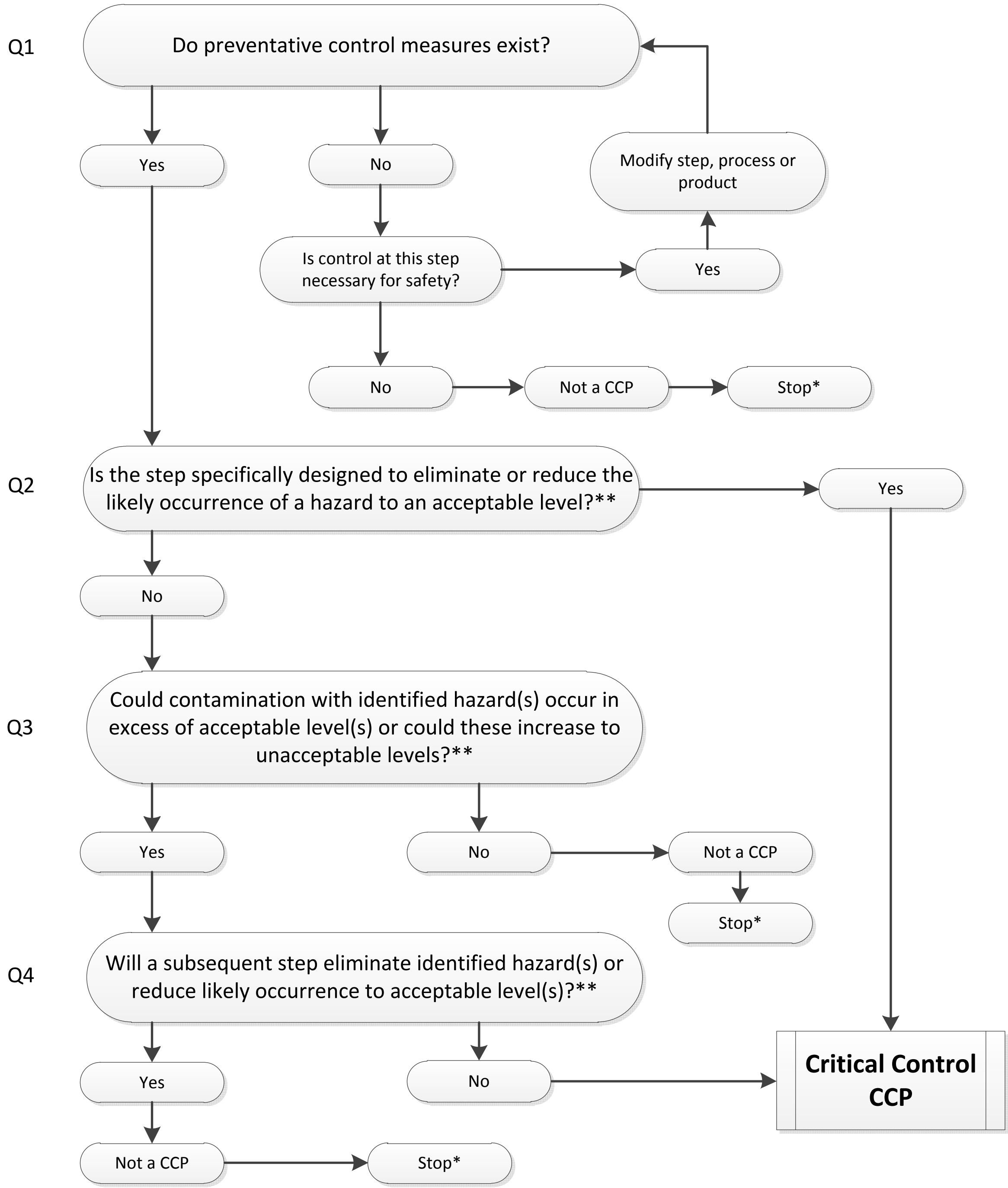

Figure 2. Decision tree to identify CCPs (FAO 2001)

2.3 Sugarcane (*Saccharum officinarum*)

2.3.1 Background

The sugarcane is a plant of the Gramineae family. The world's commercial crops of sugar cane originated with the so-called noble canes (*S. officinarum*) found in the New Guinea region. These were soft, sweet, and suited to commercial culture in tropical environments. In 1888 it was discovered that sugar cane could produce fertile seed; this began a new era in the production of hybrids. *S. spontaneum* and later *S. sinense* and also *S. robustum* (believed indigenous to New Guinea) were used in inter-specific crosses with *S. officinarum* to increase the vigour and disease resistance of the last mentioned. Today the world's sugar industries are dependent mainly on hybrid canes; many of them are made up of three species of *Saccharum* (Reid 1981).

Commercial cultivation of sugar cane is largely confined to the tropics. Outside the tropics the growth of the crop is limited by frost incidence.

2.3.2 In Australia

In Australia, sugar cane is grown mostly within 80 km of the coast, along the plains and in river valleys of northern New South Wales and Queensland (Canegrowers**¡Error! No se encuentra el origen de la referencia.**). The cane lands stretch about 2100 km in a discontinuous strip from Maclean, near Grafton, New South Wales, to Mossman, Queensland. The principal centres of production are in the neighbourhood of Cairns, Innisfail, Ingham, Ayr, Mackay and Bundaberg (Reid 1981).

Sugar cane production is limited to areas of high and evenly distributed rainfall or where irrigation is available. Rainfall ranges from 4000 to 4500 mm in the Innisfail area (Tully, Innisfail, Babinda), through 1750 mm at Cairns-Mossman and Ingham, 1500 mm at Mackay, 1100 mm at Bundaberg and 1000 mm at Ayr. All cane at Ayr is intensively irrigated. Some supplementary irrigation is also applied at Bundaberg and Mackay.

More than 4000 sugar growing farms operate along Australia's eastern seaboard. While the average size of a cane farm is 100 hectares, some are in excess of 1000 hectares. While there are still a number of smaller farms, average farm size is increasing each year, as the number of growers contracts and area farmed by their cane farming business expands. This consolidation is made possible by advances in technology, and while some corporate companies have established large cane farming operations, there are still some 6000 cane growers in Australia. The Australian cane industry produces 32-35 million tonnes of cane per year (Figure 4), which when processed, equates to around 4.5-5 million tonnes of sugar.

In 2011 there was produced 28 million tonnes (Canegrowers). Queensland accounts for about 94% of Australia's raw sugar production, New South Wales around 5% and Western Australia about 1%.

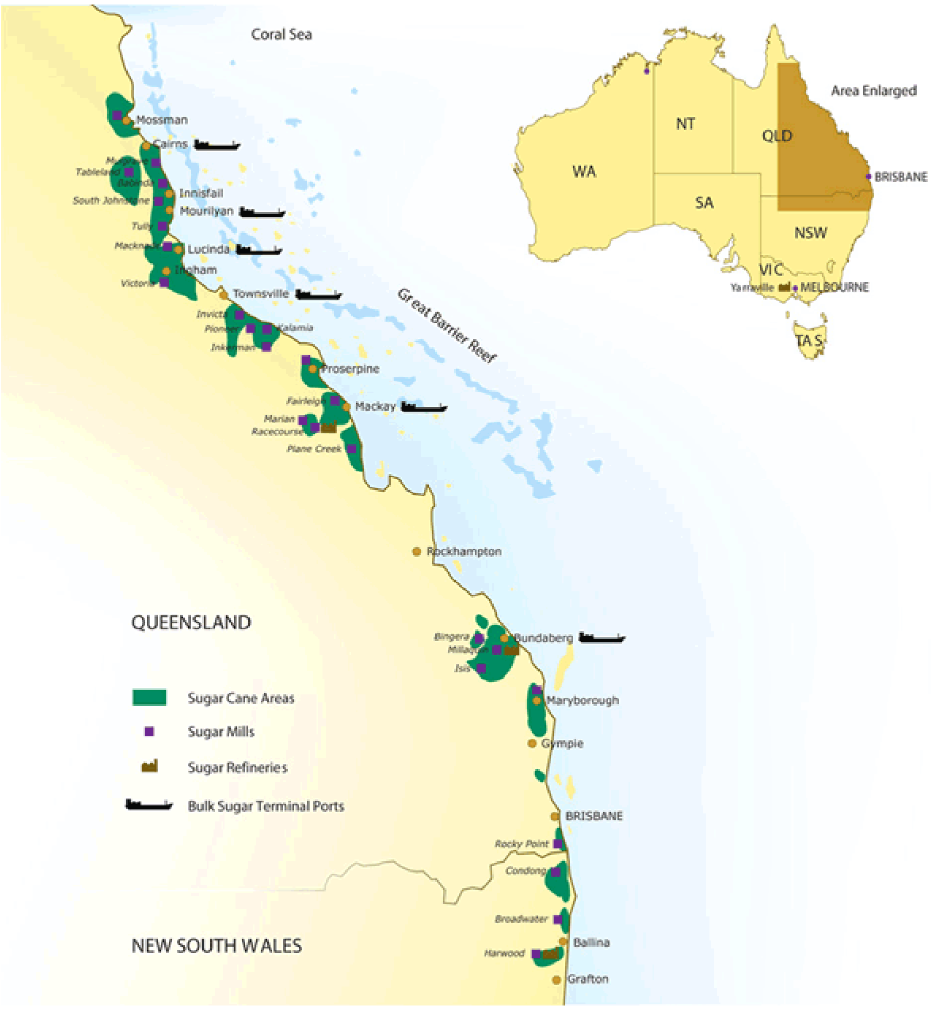

Figure 3. The cane growing regions on the NE seaboard of Australia

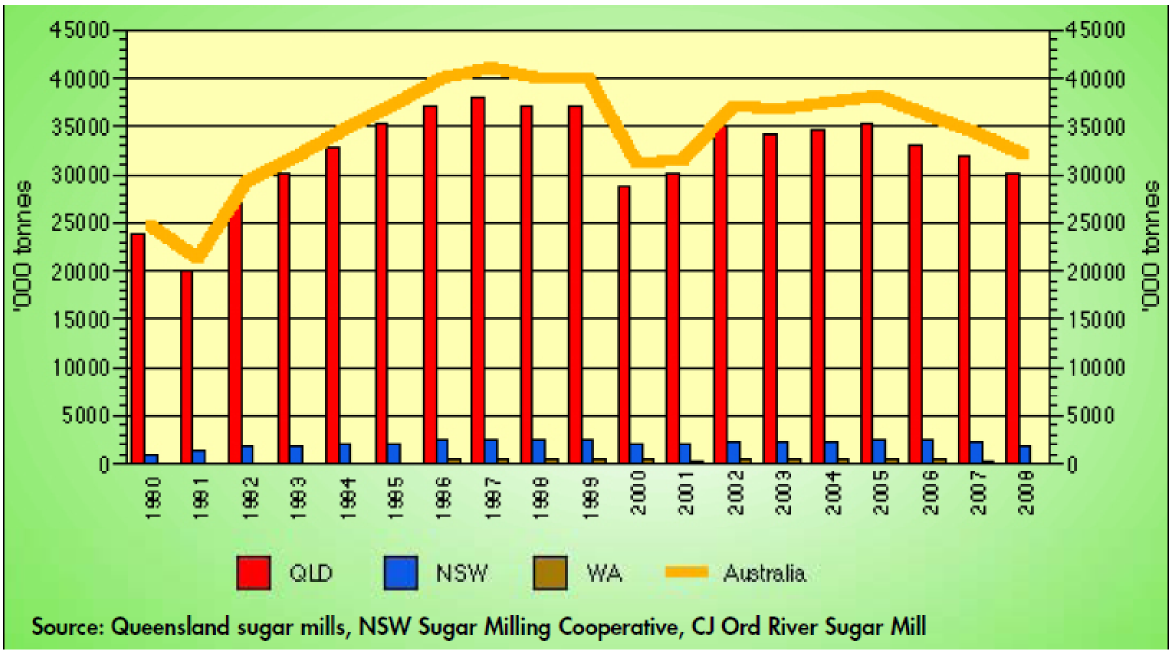

Figure 4. Australian cane production by region (Australian Sugurcane Annual 2009)

2.3.3 Planting and vegetative structure

Commercial sugar cane is propagated vegetatively. Sections of the stalk (approximately 150-300 mm long) carrying at least one bud are planted in rows with spacing between rows ranging from 1.4 to upwards of 2 m. Primary shoots from these buds are followed by secondary and tertiary shoots from the basal portion of the primaries. The resultants stool of cane produces stalks 2 to 4 m in length and 25 to 50 mm in diameter depending on the cultivar and growth conditions. Stalks are divided by nodes. The buds are auxiliary and alternate. Leaves occur at each node and the leaf sheaths encircle the stalk.

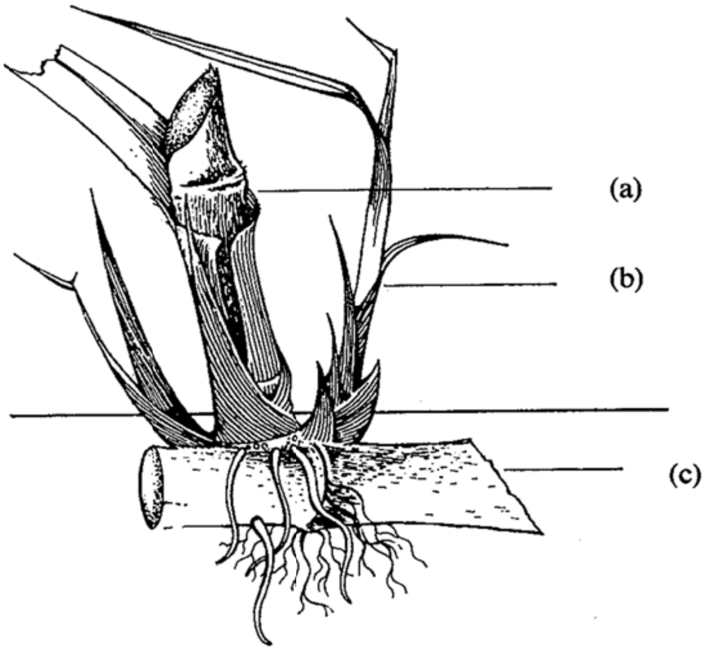

Figure 5. The sugar cane plant - (a) primary shoot, (b) secondary shoot, (c) sett

2.3.4 Cultural requirements

2.3.4.1 Climate

For good growth, sugar cane needs at least 1100 mm of rain (or irrigation) per year, warm sunny weather, freedom from frost and deep, well-drained soil. Fine, cool weather immediately before harvesting retards plant growth and increases the sugar content.

2.3.4.2 Soil

Sugar cane is a versatile crop and will grow satisfactorily on a wide range of soils. Good drainage is essential. Surface levelling and underground drainage to eliminate waterlogging are recommended practices; research has demonstrated economic yield increases from improved drainage and reduced water-tables in sugar- growing areas.

2.3.4.3 Rotation

The average crop cycle is plant and three ratoons. A legume crop may be grown in the fallow period between plough-out and replanting.

2.3.4.4 Fertilization

The crop, by virtue of the weight of green material produced per hectare, causes a heavy drain on plant nutrients. Factors influencing the amount of fertiliser applied include crop class (plant or ratoon), available moisture, previous fertiliser history and soil type. Responses from nitrogen, phosphorus and potassium fertilisers on plant crops are different from those on ratoon crops. Usually more phosphorus is applied to plant cane and more nitrogen and potassium to ratoon cane. Irrigated crops or crops grown in reliable rainfall areas can utilise more fertiliser than crops grown in drier areas (Reid 1981).

2.3.4.5 Planting rate

At 1.45 m between rows, about 5 t/ha of cane stalks are required for planting.

The billet planting machine, which uses cane stalks cut into short lengths by a chopper harvester, opens the furrow, passes the setts through a spray or bath containing a fungicidal solution, applies fertiliser, covers the setts and compacts the soil in one operation (Reid 1981).

2.3.5 Harvesting

Sugar-cane is normally harvested annually at ground level and the underground buds then shoot to a produce a ratoon crop. For Queensland, an average of three such ratoons is grown before the stubble is ploughed out and the land prepared for replanting, or a break crop. Some individual blocks of cane may be ratooned many more than three times.

Under the more temperate New South Wales climate most crops grow for 2 years before harvest and generally only one ratoon is grown.

All cane produced in Australia is mechanically harvested. The chopper-harvester removes the top, cuts the cane stalk at ground level and chops it into billets 200 to 300 mm long. Extraneous matter, mainly tops, leaves and trash, is extracted by a blast of air and the chopped cane loaded into a bin drawn alongside the harvester (Bakker 1999).

2.4 Problem statement

Farmers are too busy to attend all the manuals and specifications on the different tasks they have to carry out and industries may not have the proper methodology to detect the available technologies that will improve the management and efficiency of the farms.

There are plenty of technologies that could be readily implemented in PA systems, but farmers may not want to use them if they do not know why are they using them or if they will be able to pay them back with the potential benefits. In addition, the enormous amount of information available can make farmers unable to identify the practices that are the most important to adopt and how to apply them correctly (Banhazi and Black 2009).

2.5 Objective

Use critical control point theory to identify the technologies that are relevant to the sugarcane farming system, the key factors that are driving sugarcane production, monitor them and ensure that the correct management is in place in order to optimise production. Lastly, gather data that supports the method and keep records of the process to continuously improve the system.

This project is novel in that we will extend the HACCP concept to allow sugarcane growers to identify the most relevant PA technology for their enterprise and the most appropriate way to use that technology through a methodical framework. It will hopefully have application to numerous other industries (cotton, grain, etc.).

2.6 Research questions

1. Which are the most important problems driving sugarcane production?
2. Which are the critical points of the sugarcane production process?
3. Which are the key parameters that the farmers need to be monitoring and measuring?
4. What constraints farmer's adoption of PA?

3. LITERATURE REVIEW

Even though there are no studies for critical control point theory application addressing crop productivity, so far there have been some HACCP type approaches in the primary production sector that where conceived to meet an increasing demand by regulations and consumers regarding good agricultural practices and food safety, both in cropping and livestock systems.

In the food industry,(Toregeani-Mendes, Arroteia et al. 2011) applied a HACCP system for the control of aflatoxins in the Brazilian groundnut-based food industry, following (FAO 2001) manual (see Figure 1). The hazards involved moisture of the nuts and aflatoxin levels. For the HACCP team (step 1) they included two mycotoxicologists, a mycologist, two agronomists,a nutritionist, a toxicologist, a food analyst, a foodengineer and a statistician.They used structured interviews in order to detail industrial flow, conditions of the industry's infrastructure and knowledge level of workers with regard to the quality of groundnut-based products (step 2). In the construction of the process flow diagram (step 4) they established critical control points potential (CCPPs), that would be confirmed as critical control points on step 7 by laboratory analysis of the samples collected.Critical limits (step 8) were established for maximum moisture content of the nuts and maximum aflatoxin presence according to Brazilian standards, as well as temperature and duration of the thermal treatments. Critical limits were verified by monitoring moisture content and aflatoxins through laboratory analysis, as well as temperature and duration of thermal treatments (step 9). Corrective measures adopted (step 10) were refusal of samples, application of driers to decrease moisture content, destruction of samples with aflatoxin levels above the limit and adjust duration and temperature of the thermal treatments. No sample containing aflatoxin was found in storage after the establishment of the HACCP.

On the mushroom food industry, (Pardo et al. 2011) applied a HACCP systemon the processing line for fresh consumption. They followed the steps specified by (FAO 2001) (Figure 1) and used a decision tree (Figure 2) to determine the critical control points for microbiological, chemical and physical hazards. Asample of the results is shown in Table 1.

They recogniced 10 stages, for which they identified the hazards associated and established the preventive measures, critical levels and monitoring system if the stage was considered a CCP. Reception of the mushrooms (stage 2) was the single CCP considered in the whole process. The hazards identified were unauthorised phytosanitary products or higher doses that those allowed, as well as microbiological contamination with pathogens associated with fresh mushrooms. The preventive measures included forbidding use of unauthorised phytosanitary active matters and following factory's reccommendations on growing chambers and operators' hyigiene. The monitoring system consists on a sampling plan to control the quality of the mushrooms received, this is to monitor the toxic residues and pathogenic microorganisms. Corrective actions include refusal of mushrooms when they arrive in unacceptable conditions. Documents containing associate's details, date and time of batch received along with sanitary state will be recorded. Also all the phytosanitary products used by the farmer and the residue analysis will be recorded.

Table 1. Example of summary table of the hazard analysis (Pardo et al. 2011)

STAGE	TYPE OF HAZARD			HAZARDS	PREVENTIVE MEASURES	CP	CRITICAL POINTS	SURVEILLANCE/ FREQUENCY	CORRECTIVE MEASURES	RECORDS
	Physical	Chemical	Biological							
1. Reception and storage of auxiliary materials	X	X	X	Packaging not suitable for food use.	Official approved for suppliers	NO				
2. Reception of mushrooms		X	X	Presence of phytosanitary products	Forbiding non-authorised phytosanitary products	YES	Respect the safety doses and periods.	Visual inspection of each lot and sampling plan to ensure quality and lack of toxic residues	Rejecting or sending away unsuitable lots	Reception of lots. Incidences and corrective measures
3. Cooling			X	Altered microbials	Preventive maintenance programme for equipment	NO				
4. Dispatching to industriws			X	Microbiological contamination caused by lack of hygiene	Suitable C+D plan in the dispatching area and in the transport vehicles	NO				

In primary production, (Hegelund and Sørensen 2007) developed a HACCP-like system for improving animal health and welfare in organic egg production. According to this author, in the food industry, the risk factors (i.e. disease causing agents) are clearly defined physical entities (bacteria, metal pieces, etc.) which can be traced through the production chain. In contrast, risk factors for the development of welfare problems often comprise specific housing conditions or animal interactions which cannot be treated as yes/no entities. They used an expert panel analysis to perform the first steps of a HACCP analysis, including defining the health and welfare problems, defining and evaluating risk factors for the problem, defining critical control points and choosing alarm values for the critical control points. The experts were contacted via email and were anonimous to each other.The design of each questionnaire (a total of four) was dependent of the answers of the previous questionnaire and the method has many similarities with a delphi approach. The level of consensus reached in the answers of each questionnaire was measured using the interquartile range (IQR). In questionnaire 1, a list aimed to include the health and welfare problems seen in Danish organic egg production was assembled and sent to the experts, who were asked to score each of the 34 problems according to severity and frequency using a five-point scale: 5 very severe/very frequent, 4 severe/frequent, 3 moderate/regular, 2 less severe/ rare, 1 not severe/very rare. For questionnaire 2, the median values of severity and frequency from the previous questionnaire were calculated for each problem and based on these scorings, the most important health and welfare problems were selected (maximum of 10). The experts were also asked to suggest risk factors for these problems. Questionnaire 3 included lists of risk factors for each problem. Experts were asked to score each risk factor with respect to severity and frequency, scored on a four-point scale: 4 severe/frequent, 3 moderate/regular, 2 less severe/rare, 1 not severe/very rare. With the results, the median values of severity and frequency were calculated and risk factors were chosen based on their scorings. In the last questionnaire, experts were asked to list all possible control points in as much detail as possible for each risk factor and also suggest alarm values for each control point.

(Galan et al. 2003) used the HACCP methodology for quality, risk control and sanitary safety in agriculture, and as a method for identification and prioritization of risks. They suggest two possible strategies: (i) apply a conventional HACCP method;hazard analysis and identification of critical points. (ii) Apply a list of preventive measures, identified beforehand during a hazard analysis performed on a local or regional level, by a group of experts, regardless of the production system. The application of the HACCP method is defined as the development of a referential for good practices.

An example of the second strategy is the Quali'Terre referential, which was done in three stages (Table 2): theoretical hazard analysis and identification of possible actions, prioritization of risks and assessment of actions on a regional scale and application on the farming system level.

Table 2. The operational steps followed for the conception and development of the Quali'Terre referential (Galan et al. 2003).

	The stages of design and application of the Quali'Terre referential	
Step 1	Theoretical analysis	Consultation of scientific experts (INRA): September-December 1997. Theoretical analysis of HACCP on extensive cropping systems:1st semester 1998. Elaboration of a 1st version of the referential: June 1998.
Step 2	Regional analysis	Validation by a group of advisors: hierarchization of risks and evaluation of possible actions at a regional scale. June to December 1998.
Step 3	Feasibility	Feasibility test with 110 farms to validate the formulation of questions and their comprehensiveness: February-June 1999.
Step 4	Official launch	Launching of the method in Picardie: December 1999

(Leifert et al. 2008) used a HACCP-based approach to control enteric pathogens in ready-to-eat vegetable crops in organic and low input production systems. They report various approaches to assess the potential risks of pathogen transfer:

- Statistics/literature reviews of reported cases of foodborne diseases.
- Microbiological assessments/surveys of contamination levels in specific foods.
- Hazard analysis-based risk assessments which evaluate/compare risks of pathogen contamination at specific Critical Control Points.

In the meet industry, (Horchner and Pointon 2011) developed a HACCP-based program for on-farm food safety for pork production in Australia. They applied the HACCP methodology at an overall livestock sector level according to (FAO 1998), which implies the logic sequence for application of HACCP (Figure 1). The HACCP team (step 1) was selected on the basis of having experience in the development of HACCP systems. Verification of the process flowchart (step 5) was undertaken by desktop review by industry stakeholders. Principle 1 (step 6), hazard analysis, was conducted from a literature review and the published public health surveillance data in Australia. In addition, hazards identified and classified as being relevant were assessed using an on-farm hazard decision tree (Figure 6). For Principle 2 (step 7), determine critical control points, another decision tree was used (Figure 7). The remaining HACCP principles were applied as specified by(FAO 1998).

Other studies, like (Campden BRI 2009) suggest 14 steps to apply the principles of HACCP in agriculture for the safety and quality of food. However, these steps are the same ones presented in Figure 1 with two previous steps: (i) Obtain senior management commitment and (ii) define the terms of reference/scope of the study. After these two steps, the next 12 steps are applied as shown in Figure 1.

(Banhazi and Black 2009)pointed in their study that a rigurous application of the HACCP principles would increase productivity and profitability on livestock farms, mainly due to the assurance of carrying out correctly the most essential tasks through the application of current knowledge and technologies. This approach, they believe, will provide the structure that would allow to make use of the vast information available on the farming systems.

From the literature presented above, some general points can beextracted:

- So far there have been experiences of HACCP methodology application in agriculture, but focused on food safety.
- The methodology used in all cases follows the logic sequence of HACCP application of Food and Agriculture Organization of the United Nations (Figure 1).
- CCPs may be determined using decision trees or expert panel analyses.

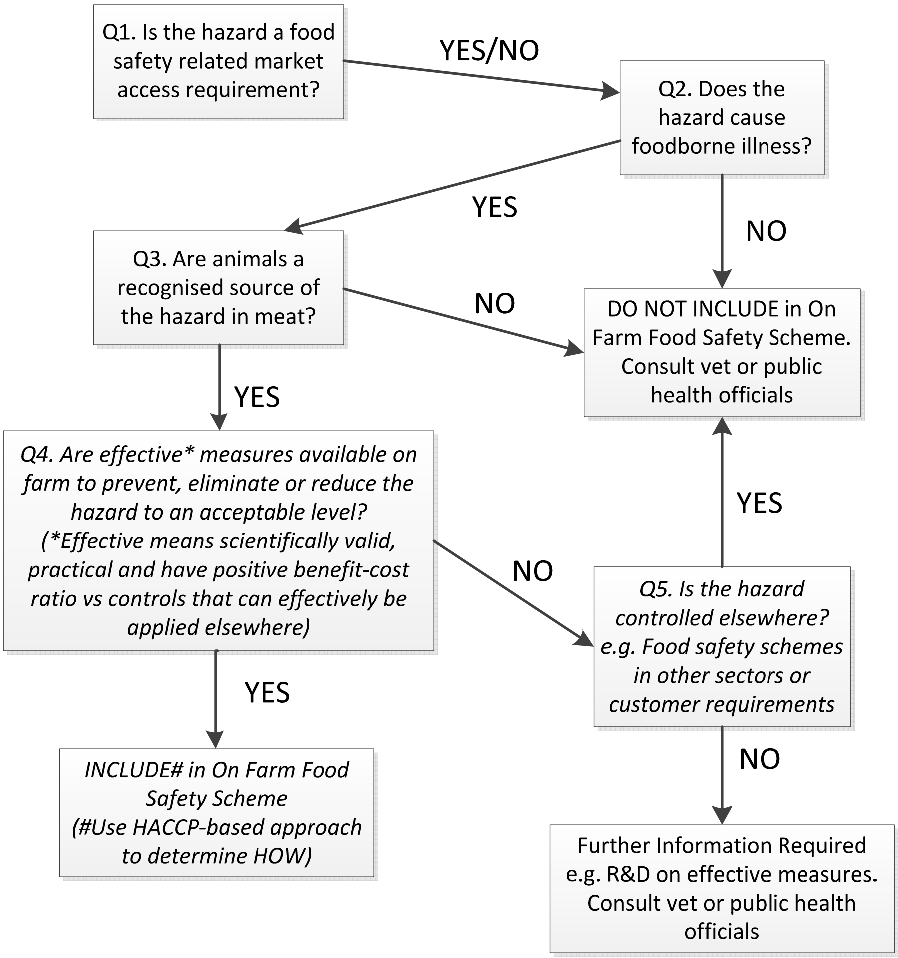

Figure 6. On-farm food safety system hazard decision tree (Horchner and Pointon 2011)

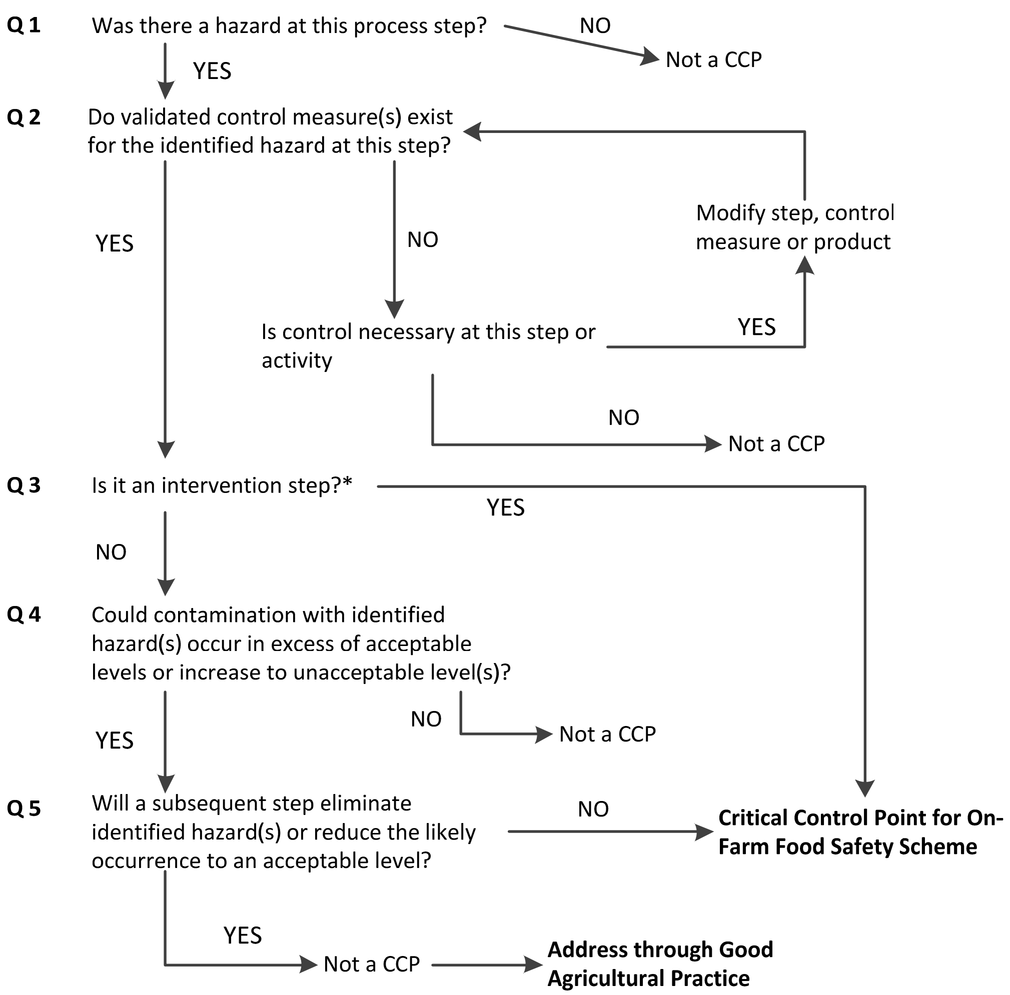

Figure 7. Critical Control Point decision tree (Horchner and Pointon 2011)

4. METHODOLOGY

In the food industry, the HACCP system tends to be very specific around one item, whereas in a cropping situation there is irrigation, pests/diseases, weeds, and many other factors that have to be managed, as well as factors that cannot be managed at all, such as the climate. The new framework will be applied across all of those to help identify which are the most appropriate technologies that will allow managing them properly.

The methodology will be based on the one proposed by (FAO 2001) and will be structured in such a way that the most suitable options taken from the literature are merged into a single frame for a cropping system. However, emphasis will be placed on the fact that risks cannot be fully prevented, eliminated or reduced to an acceptable level. Therefore, the focus is more on reducing the likelihood of introduction of a hazard.

In addition, there are several factors directly influencing crop production that are not process steps as such. These are soil related factors such as soil type and pH as well as environmental factors, such as rainfall, temperature, solar radiation etc. Therefore, special steps will be designed to address every specific factor that influences yield throughout the whole process.

The first five steps are planning stages to enable the hazard analysis. From these, only the fourth and fifth steps (construction of flow diagram and confirmation of flow diagram) will be carried out in this report. The first three steps (Assemble HACCP team, product description and intended use of the product) should be carried out for each specific farm for which the plan is implemented.

The last 7 steps are the implementation of the HACCP plan.
The HACCP system has a widespread adoption in the food industry. Hence, there are plenty of studies focusing on this system ((Galan et al. 2003; Horchner et al. 2006; Hegelund and Sørensen 2007; Leifert et al. 2008). In most cases they follow the guidelines suggested by FAO (2001). This MSc Thesis, because it is exploring a less conventional application of this system, it is based on those guidelines and has combined the methodology followed in other studies to adapt it to this new approach. However, it is emphasized that certain hazards for crop production cannot be avoided, reduced to an acceptable level or fully prevented. Therefore, it is focused on reducing the likelihood of introduction of hazards or risks.

The first step is the assembly of the HACCP team. In this case, being a preliminary study, the team will consist in one person, although external expertise will be used to ensure the effectiveness of the plan. On the one hand, agronomy experts will be contacted that will suggest which are the most important operations growers carry out in relation to the yield. On the other hand, growers will be contacted to identify what is, to their opinion, the most important tasks driving the production. This is consistent with the guidelines presented by Campden BRI (2009).

This study will assess those hazards that constraint an optimum yield, starting from the planting of the sugarcane and until the harvested crop is deposited in the bins for transport to the mill. It will also identify what is constraining the adoption of PA by farmers, in order to better design strategies that focus on the most important issues.

However, for the implementation of this methodology in a specific farm, a multi-disciplinary team should be assembled with experts covering the main hazard areas, such as irrigation, harvesting, general agronomy, etc.

The second step suggested by FAO (2001) is a description of the product. In this case the product under study is sugarcane. Sugarcane is described in Chapter 1.3. However, as this work is oriented to the industry, experts and farmers, who have and extended knowledge about sugarcane, this step can be ignored.

The third step details the intended use of the sugarcane. The sugarcane is to be carried to the mill right after harvesting to obtain the sugar from its juice. As in the previous step, it is not necessary to address this step in too much detail.

The fourth and fifth steps are the construction of a flow diagram of the process and its verification. The flow diagram of the process is presented in Figure 8. For the construction of this flow diagram, MS Visio 2010 software was used. According to FAO (2001), the flow diagram must be confirmed against the actual operation and be amended where appropriate. However, as it is stated in Campden BRI (2009), “crop production is a time based operation and it is clearly not possible to observe every relevant step in the production process at a single point in time, as it could take a whole season.” Therefore, the flowchart verification will be undertaken by desktop review experts and farmers (Horchner and Pointon 2011).

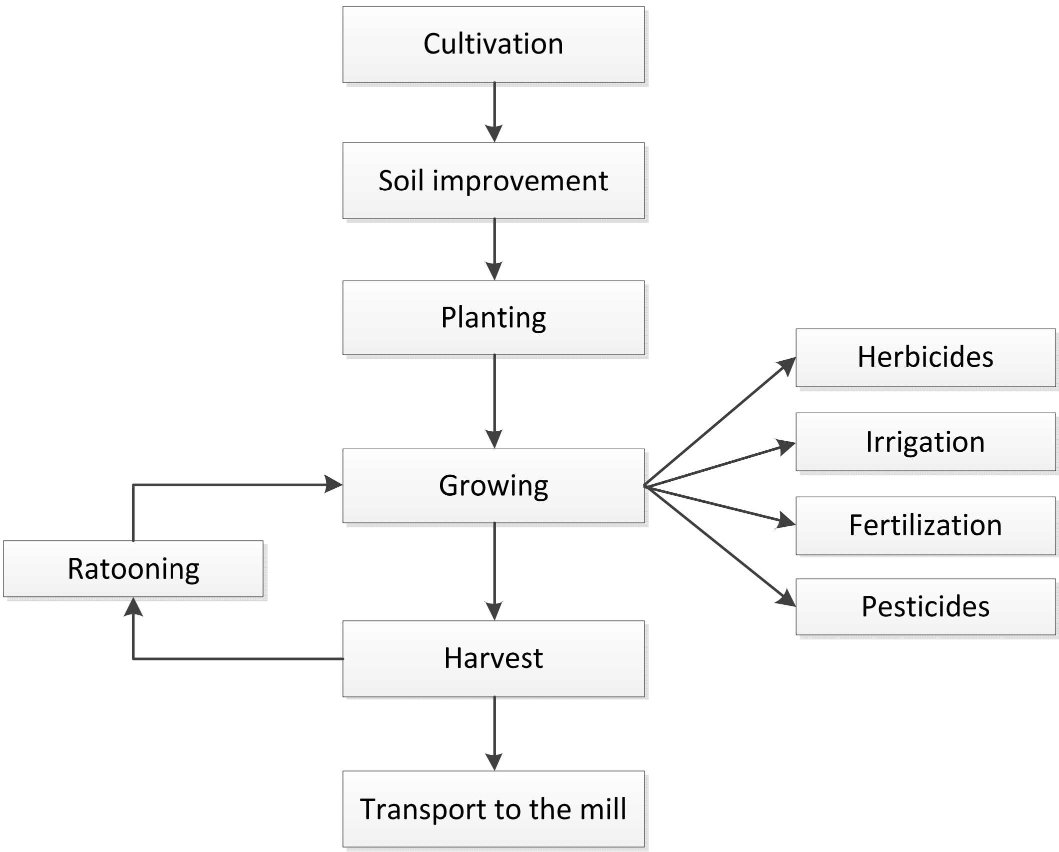

Figure 8. First process flow diagram

The sixth step is to list all potential hazards (HACCP PRINCIPLE 1). This step requires to list all the hazards that may be expected to occur at each step. It also requires to conduct a hazard analysis to identify which hazards are of such a nature that their elimination or reduction to acceptable levels is essential.

Expert panel analyses can be used to analyse situations where empirical data are too scarce to perform traditional statistical analyses (Vose, 2000 in (Hegelund and Sørensen 2007)). As a novel approach, the method chosen was a series of questionnaires for experts' consultation. A list of problems was assembled through literature review and preliminary expert consultation. These problems were addressed by experts and farmers via questionnaires and were be used to identify the most important problems driving productivity, the risk factors for these problems, the severity and frequency, and also to list control points for the risk factors as well as alarm values for these control points. The aim is to identify from the original full list of problems the most important issues and focus the HACCP plan on those.

Four questionnaires were made in a similar approach as Hegelund and Sørensen (2007), where the first three questionnaires were used to carry out the HACCP Principle 1 and the fourth questionnaire the HACCP Principles 2 and 3.

Questionnaire 1. The first questionnaire consists of two independent lists. The first one addresses 48 productivity hazards that are likely to be found throughout the sugarcane production process (Table 3), such as water availability, pests, etc. The second list addresses nine hazards that can potentially limit the adoption of PA by farmers (Table 4). The objective of these lists is to, on the one hand, identify the most important problems driving sugarcane productivity according to experts and growers and, on the other hand, identify the most important problems constraining the adoption of precision technologies. These problems were asked to be scored according to severity (how important is the problem) and frequency (how often does it occur) using a five-point scale: 5 very severe/very frequent, 4 severe/frequent, 3 moderate/regular, 2 less severe/ rare, 1 not severe/very rare.

The level of consensus is measured using the interquartile range (IQR), as follows: IQR ≤ 0.5: strong consensus, $0.5 < \text{IQR} \leq 1$: moderate consensus, IQR > 1: no consensus.

To ensure that the expert panel would include different perspectives that would point important aspects for the industry in general, experts, researchers and growers were contacted and from different locations in Queensland. Contacts had a link with other PA projects with NCEA. The aim was to include up to 10 persons in the panel. Given the extreme distances between different locations (up to 1,500 km.), some interviews were performed face to face and others via e-mail.

Questionnaire 2. The second questionnaire was assembled according to the responses in Questionnaire 1. The median values of severity and frequency were calculated for each problem from the first questionnaire. Based on these scorings, the most important problems of production and for PA adoption were selected (10 maximum for productivity problems and 4 in the case of PA adoption issues). First, the most severe (scoring 5) and most frequent (scoring 5) were selected. Key drivers, or risk factors, had to be suggested for the selected problems (

Table 7).

Questionnaire 3. The third questionnaire consisted on merging in a list the key drivers suggested in the second questionnaire. Again, as in the first questionnaire, this list of risk factors, both for productivity issues and adoption of PA, was asked to be scored according to severity and frequency using a five-point scale.

The median values of severity and frequency were calculated for each risk factor. The ten most important key drivers for productivity and the four most important technological problems were selected as the list of potential hazards (HACCP Principle 1). Due to a larger number than expected of suggested risk factors, only six productivity problems were selected for further analysis. This was to ensure an acceptable size of the questionnaire.

Questionnaire 4. The fourth and last questionnaire was again assembled according to the results obtained in the third questionnaire. This last questionnaire would help to determine Critical Control Points (PRINCIPLE 2) and establish Critical Limits for each Critical Control Point (PRINCIPLE 3). This questionnaire listed the ten most important productivity risk factors and the four most important technological problems for PA adoption. For each of them, and with the help of Figure 9, also included as part of the questionnaire, was asked to identify the critical control points within the process flow diagram (Figure 9) as well as the alarm values within which the process would be considered under control.

Once all this data is gathered and analysed for productivity problems, it must be established a monitoring system for each Critical Control Point (PRINCIPLE 4), the corrective measures (PRINCIPLE 5), the verification procedures (PRINCIPLE 6) and the documentation and record keeping (PRINCIPLE 7). One risk factor will be selected for this study in order to fully demonstrate the application of the HACCP system. The most important risk factor identified on the previous step (Questionnaire 3) will be selected and will be used as an example for oncoming HACCP steps, with the help of experts and growers.

At this step, current technologies available to monitor the selected risk factor were review and suggested. This is to describe what is going to be measured and how the monitoring process is carried out. It also describes the methods that confirm the Critical Point is under control, the frequency of the monitoring as well as the documentation of the records that will be necessary to keep in order to be verified at a later stage.

5.RESULTS AND DISCUSSION

5.1 Amended process flow diagram

With the help of growers and experts, the initial process flow diagram was amended and improved the level of detail (Figure 9). This process flow diagram is a key part of a HACCP plan and must be taken into account at a later stage to identify the critical control points within this process. There are six key steps in the operation. These comprise land preparation, cultivation, planting, growing/general agronomy, harvest and transport to the mill.

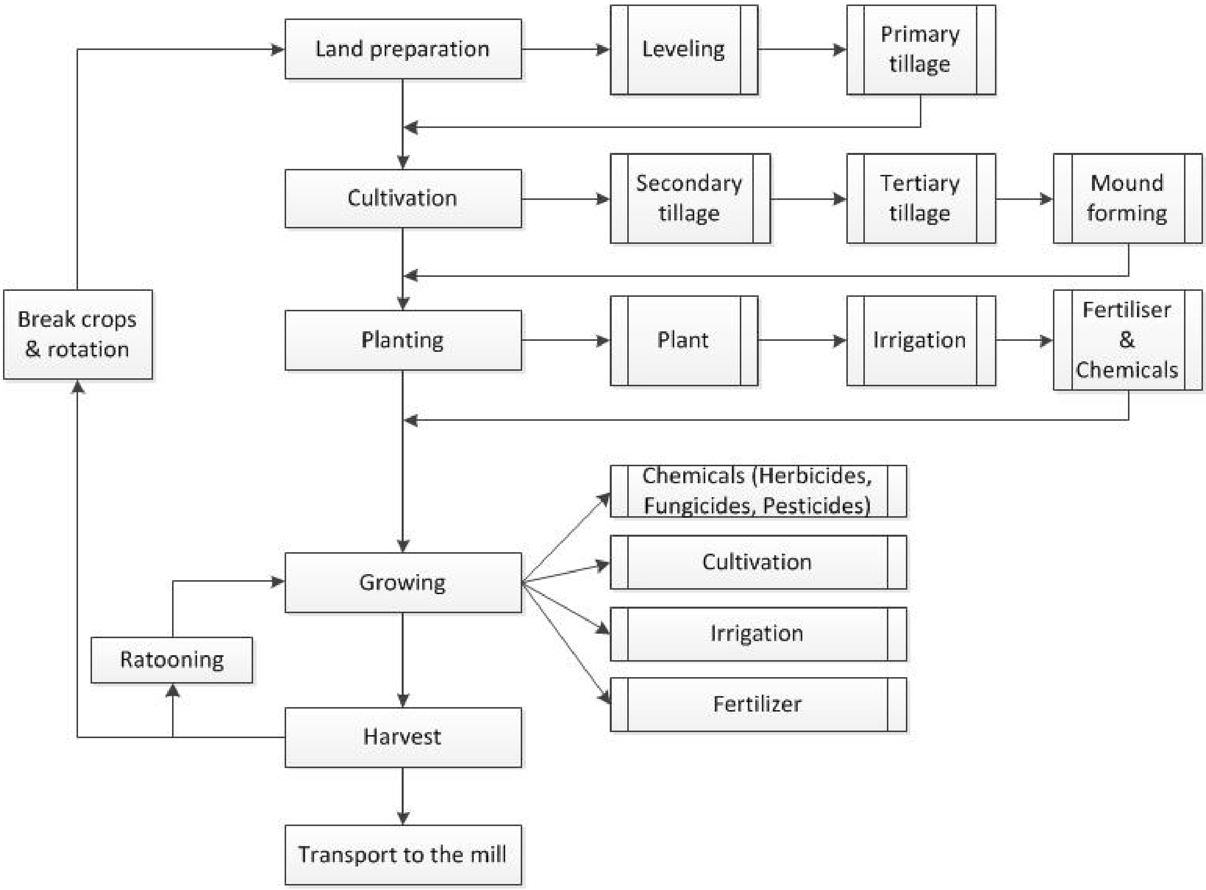

Figure 9. Amended process flow diagram of sugarcane production

5.2 List of potential hazards (PRINCIPLE 1)

5.2.1 Questionnaire 1

The list of potential hazards is shown in Table 3. This list was used to carry out the first questionnaire and identify the most important problems driving sugarcane production.

Table 3. List of potential hazards found in a Sugarcane farm (Questionnaire 1)

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Soil pH		
2	Soil type (texture)		
3	Soil bulk density (compaction)		
4	Soil CationExchange Capacity		
5	Soil Organic Matter		
6	Soil erosion/degradation (Wind/water erosion)		
7	Contamination of soil (pesticides/herbicides/fertilization)		
8	Soil salinization		
9	Intoxication of plants (pesticides/herbicides)		
10	Contamination of environment		
11	Acid Sulphate Soils		
12	Soil depth		
13	Pests		
14	Diseases		
15	Weeds		
16	Water availability		
17	Water quality		
18	Irrigation system		
19	Drainage/Waterlogging		
20	Runoff/leaching/loss of nutrients/groundwater contamin.		
21	Topography		
22	Fertilization/Fertilization type		
23	Harvesting date		
24	Harvest green cane / burnt cane		
25	Variety selection		
26	Crop rotation		
27	Ratoon number		
28	Planting (density, row spacing, costs, establishment)		
29	Loss of contaminants		
30	Distance to rivers/sea/wetlands/forests		
31	Presence of endangered species		
32	Protected areas		
33	Noise		
34	Air pollution		
35	Disposal of used materials/Waste management		
36	Rainfall		

37	Temperature		
38	Hail		
39	Solar radiation		
40	Proper machinery		
41	Fallow		
42	Technologies		
43	Manager's tools		
44	Manager's knowledge		
45	Harvesting losses (ground job, chopper losses, forward speed, extractor losses,…)		
46	Harvesting costs		
47	Performance of chemical application		
48	Natural calamities (cyclones,excessive rainfall, drought,…)		

In Table 4 the list of technological problems constraining the adoption of Precision Agriculture by farmers is shown. This list was also used in Questionnaire 1 together with Table 3.

Table 4. List of technological problems (Questionnaire 1)

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Obsolescence		
2	Compatibility		
3	Knowledge of what equipment can do		
4	Knowledge of what you do with the answer/output		
5	Suitability of equipment (specificity/sensitivity for the actual crop)		
6	Support		
7	Cost		
8	Yield monitors		
9	Yield/Cost/Profit or other benefit (legal, environmental…)		

Nine responses were received. From the problems list in Questionnaire 1 (Table 3), the top ten were identified according to the scorings of severity and frequency (Table 5). These were harvesting losses, harvesting costs, variety selection, rainfall, soil bulk density (compaction), pests, manager's knowledge, weeds, diseases and harvest date. There were between 8 and 9 responses to calculate these problems. The IQR index showed an acceptable general consensus, being four problems with no consensus (IQR>1) for severity and only one problem with no consensus for the frequency. The problem with highest scoring was "harvesting losses" and shows a high degree of consensus both in severity (0.25) and in frequency (0.25). This suggests that the problem is very severe / very frequent for the sugar industry regardless of the geographic location of the farm.

From the technological problems list in Questionnaire 1 (Table 4), the 4 most important were selected (Table 6). These were compatibility of equipment, knowledge of what to do with the answer/output, cost of equipment and profit gained by the use of the technology.

These problems have the highest median and average values according to the results obtained with the questionnaires. There were between 7 and 9 responses for each problem that were used to calculate these values. In all cases the IQR shows a moderate/high degree of consensus.

Table 5.Scorings of the 10 most important problems driving sugarcane production

		Severity				Frequency			
	TOP PROBLEMS	*n*	*Median*	*Avg*	*IQR*	*n*	*Median*	*Avg*	*IQR*
1	Harvesting losses	8	4	4.25	0.25	8	4	4.13	0.25
2	Harvesting costs	8	4	4.13	1.25	8	4	4.25	1
3	Variety selection	8	4	3.88	1.25	8	4	3.88	1.25
4	Rainfall	9	4	3.78	1	9	4	3.67	1
5	Soil bulk density (compaction)	9	4	3.67	1	9	4	3.67	1
6	Pests	9	4	3.44	1	9	4	3.78	0
7	Manager's knowledge	8	4	3.88	1.25	8	3.5	3.50	1
8	Weeds	9	4	3.44	1	9	4	3.33	1
9	Diseases	9	4	3.22	2	9	4	3.44	1
10	Harvesting date	8	4	3.38	1	8	3.5	3.38	1

Table 6.Scorings of the 4 most important technological problems.

		Severity				Frequency			
	TOP PROBLEMS	*n*	*Median*	*Avg*	*IQR*	*n*	*Median*	*Avg*	*IQR*
1	Compatibility	9	5	4.33	1	9	4	3.67	0
2	Knowledge of what you do with the answer/output	9	4	3.89	0	9	4	3.67	1
3	Cost	8	4	4	0.5	8	4	3.63	1
4	Yield/Cost/Profit or other benefit (legal, environmental,…)	7	4	4	1	7	4	4	0

5.2.2 Questionnaire 2

In Table 7 and Table 8 an example of a completed second questionnaire is shown. Table 7 lists the ten most important problems driving sugarcane production identified in questionnaire 1 (Table 5) and the aim was to collect risk factors or key drivers for each of the selected problems.

Table 8 lists the four most important technological problems constraining the adoption of PA identified in questionnaire 1 (Table 6) and the aim was also to collect risk factors or key drivers for each of the selected problems. There were nine responses collected with risk factors suggested for productivity problems and eight responses with suggestion of risk factors for technological problems.

Table 7. Example of a completed second questionnaire for sugarcane production

nr	*Problem*	*Risk factors*
45	Harvest losses	- Significant loss of crop already grown and paid for - Increased harvesting costs
51	Harvest costs	- Increased fuel costs - No “bonus” for a good job - Supply of drivers
25	Variety Selection	- Disease resistance - New varieties unproven on farm
38	Rainfall	- Too much - Too little - Not being able to adapt to forecasts
3	Soil bulk density (Compaction)	- Machinery driving over stool - Reduced productivity - Increased water runoff, decreased infiltration
13	Pests	- Cane grubs controlled - Few chemicals - Pest incursion
46	Managers knowledge	- Not current - Can be one dimensional - Doesn’t know what he doesn’t know
15	Weeds	- Loss of crop production - Wasted water & fertilizer - Weed seed bank
14	Diseases	- Disease outbreak - Disease incursion - Cost associated in changing to “new” resistant varieties

Table 8. Example of completed Questionnaire 2 for the technological problems

nr	*Problem*	*Risk factors*
2	Compatibility	- Farmers GPS - contractors GPS units need to communicate - Transfer of data without distortion - Add on equipment suitable for all makes/ models
3	Knowledge of what equipment can do	- Sticking to what we know. - Limited after sales support - Unwillingness to get educated on new ideas
4	Knowledge of what you do with the answer/output	- Ignorance - Is the info useful or applicable - Is the output accurate - reliable - Can I get the same answer easier – KISS technology
6	Support	- After sales support important - Upgrading software over time - Informing – education of customers - Growers need to be informed of technology improvements

Questionnaire 2 resulted in a total of 353 suggested risk factors including several doublets. 273 of these were factors associated with farm productivity and 80 related to constraints to the adoption of PA technologies, as can be seen in Figure 10. This is 39.3 suggested risk factors per response. After editing, the risk factors selected for the most important productivity problems were 92, distributed on the following six groups: harvest (30), variety selection (17), rainfall (5), compaction (13), pests (16) and manager's knowledge (11). The risk factors selected for the PA adoption constraints were 31, distributed on the following four groups: compatibility (9), knowledge of what to do with answer/output (15), benefits obtained with the technology (5) and cost (2).

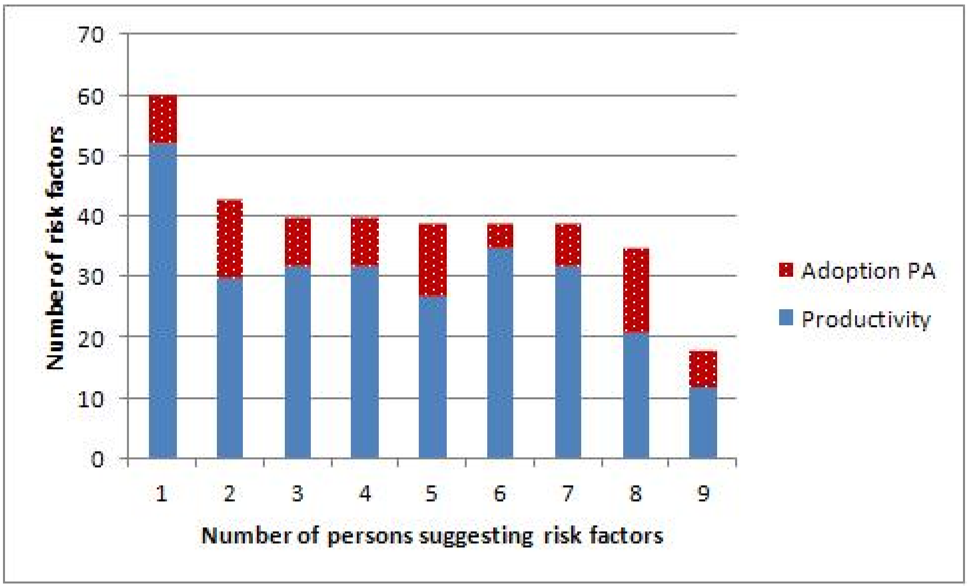

Figure 10. Distribution of number of risk factors suggested by between one and 13 experts in the panel

5.2.3 Questionnaire 3

The lists of 92 productivity problems and 31 technological problems were scored by the expert panel. This time five responses were received to calculate the final scorings. A decrease in the number of responses is a common phenomenon among the studies that use a series of questionnaires (Hegelund and Sørensen 2007). There was consensus on 65 out of the 92 productivity risk factors when scoring severity and on 62 when scoring frequency. There was consensus on 24 out of the 31 technological risk factors when scoring severity and 25 out of 31 when scoring frequency. This suggests that most of the risk factors are perceived in a similar way, despite the different perspectives. However, although very few, there are among some of the answers in the questionnaire some risk factors with totally opposite scorings. This suggests that the way a risk factor is perceived can be a key issue when it comes to subjectively score the severity and frequency, that can be perceived with the wrong mind set, or even that the way a questionnaire is presented has an effect on how certain risks are perceived, giving a scoring that has little to do with reality. Nevertheless, the overall good consensus indicates that in those cases that there is no consensus, it can be accused to the geographic distances or the different perspective of growers and experts.

Ten risk factors were selected for productivity issues (Table 9) and four for technological problems (

Table 10). Among these selected risk factors, there was consensus on seven out of the ten productivity factors for severity and eight for frequency. For technological factors, there was consensus on three out of four factors both for severity and frequency.

The selected risk factors for sugarcane productivity problems belonged to just two problem categories: harvest and compaction. The median values of these risk factors were between 4 and 5. The average values ranged between 3.6 and 4.6. All four compaction problems selected showed a high degree of consensus.

The four most important risk factors regarding the technological problems also belong to two problem categories: cost of equipment and the profit obtained with the use of the technologies. The median values are between 4 and 5. The average values range between 3.8 and 4.4. Issues related to the cost of equipment showed a high degree of consensus (IQR ≤ 1) whereas the risk factors related to the profit obtained by the use of the technology show a low degree of consensus (IQR > 1).

All this indicates that the overall opinion of the participants is strongly pointing to specific issues. However, surprisingly there were no risk factors pointing to water availability or irrigation issues. This is generally accepted as a critical problem for any sugarcane farm (Craig Baillie, NCEA Director, personal communication). This can be explained by the comments before, as being such an obvious issue it is not even considered as such because there are already plenty actions addressing this problem. This makes the handling of the results obtained very carefully and suggests that future studies in this regard should be done in the most objective possible way with a multidisciplinary team, in which the actual economic impact of every risk factor is assessed.

The risk factor with highest score and with a moderate consensus is "sugar loss in field" during harvest. This means that from every perspective, this risk factor should be addressed first to improve sugarcane productivity.

Table 9. Top ten risk factors for productivity problems

			Severity				Frequency			
nr	*Problem*	*Risk factor*	*n*	*Median*	*Avg*	*IQR*	*n*	*Median*	*Avg*	*IQR*
1	Harvest	Sugar loss in field	5	5	4.6	1	5	4	4.2	1
2		Harvester design	5	4	3.6	2	5	5	3.8	2
3		Stool damage – harvest too fast, blunt base cutters, driving haul outs on stool	5	4	4.2	0	5	4	4.2	1
4		Lack of value chain acknowledgment	5	4	4	2	5	4	4	1
5		Inefficiency	5	4	3.8	1	5	4	4	2
6		Operator knowledge/training, experience	5	4	3.8	2	5	4	3.8	1
7	Compaction	Reduced productivity	5	4	4.4	1	5	4	4	1
8		Controlled traffic	5	4	4.2	0	5	4	4	0
9		Machinery driving on stool	5	4	4.4	1	5	4	3.8	0
10		Heavier machinery	5	4	4	0	5	4	4	0

Table 10. Top four technological problems constraining the adoption of PA by farmers

			Severity				Frequency			
nr	*Problem*	*Risk factor*	*n*	*Median*	*Avg*	*IQR*	*n*	*Median*	*Avg*	*IQR*
1	Profit	Government regulations	5	5	4	2	5	5	4.2	1
2		Perception by the grower	5	4	4.2	1	5	4	4	2
3	Cost	Small farm size to just expenses for PA and other issues	5	5	4.4	1	5	4	3.8	0
4		Uncertain return on investment	5	4	4	0	5	4	4	0

5.3 Determine Critical Control Points (Principle 2)

5.3.1 Questionnaire 4

With the results obtained in questionnaire 3 (Table 9 and

Table 10), the last questionnaire was assembled. The aim of this last questionnaire is to identify, with the use of the sugarcane production flow diagram (Figure 9) the critical control points within the process as well as the alarm values that will indicate that the hazard under study is under control.

Only three responses were received, all of them from the Herbert region in North Queensland. This time all responses are from experts. No responses were received from growers.

Little diligence was put into following the directions on how to address the questionnaire with the aid of the amended process flow diagram (Figure 9), although most of the Critical Points were located at the harvest stage as expected. However, there were also some CCPs not applicable within the scope of the study, such as the harvester design.

Many alarm values were not accurate enough or didn't guarantee to control the problem early enough, such as "management has no knowledge of issues", "poor planning", "slow tractor speed" or "poor ratooning". In this last example, for "stool damage", it is obviously a consequence of this damage why is observed a poor ratoon and it is too late to apply any corrective measures. The suggestion of inaccurate alarm values is common in questionnaire responses (Hegelund and Sørensen 2007). Other alarm values suggested to control stool damage would be not to drive a tractor above 7 km/h and not to drive over recently harvested plants.

Table 11. Selected risk factors to determine their Critical Control Point(s) and alarm value(s)

nr	*Problem*	*Risk factor*	*Control Point(s)*	*Alarm value(s)*
1	Harvest	Sugar loss in field		
2		Harvester design		
3		Stool damage – harvest too fast, blunt base cutters, driving haul outs on stool		
4		Lack of value chain acknowledgment		
5		Inefficiency		
6		Operator knowledge/training, experience		
7	Compaction	Reduced productivity		
8		Controlled traffic		
9		Machinery driving on stool		
10		Heavier machinery		

There were not enough responses to compare the answers of the different alarm values suggested. However, at this stage of the process it is not necessary as it is demonstrative of the application of the system. Moreover, to fully establish proper alarm values in a sugarcane farm situation, it would be necessary to review the relevant literature of the location where the farm is located and the input of experts. In many cases, furthermore, it would be necessary a preliminary research on the risk factors in order to determine the optimum alarm values.

6.CONCLUSION

This is a guideline that intends to show the application of Critical Control Point theory as a tool to increase the profitability and sustainability of cropping enterprises, in this case sugarcane, in the context of Precision Agriculture (PA) and with the help of new and emerging technologies. This is a first step towards a bigger scale development and on-farm implementation starting July 2013.

The ten most important key drivers for sugarcane productivity have been identified to potentially focus the methodology in order to test it. These are, sorted by importance:

1. Harvesting losses
2. Harvesting costs
3. Variety selection
4. Rainfall
5. Soil bulk density (compaction)
6. Pests
7. Manager's knowledge
8. Weeds
9. Diseases
10. Harvest date

For this instance, one of the most important productivity hazards has been selected to run the methodology through all the steps involved. Also, this report should be considered a general frame were common problems are suggested. It is acknowledged that very important hazards for a given location might not be included here and so it is recommended a very detailed study of every specific farm subject to implementation of this methodology, rather than just following the hazards identified here.

The risk factors, within a problem, that should be monitored and controlled are the following:

- Harvest:
  - Sugar loss in field
  - Harvester design
  - Stool damage
  - Lack of value chain acknowledgment
  - Inefficiency
  - Operator knowledge/training, experience
- Compaction:
  - Reduced productivity
  - Controlled traffic
  - Machinery driving on stool
  - Heavier machinery

Some risk factors identified in this study, such as machinery design, cannot be controlled during the sugarcane production process and therefore the HACCP plan cannot be applied to those risk factors.

Water availability, "Rainfall" in this case, was the fourth most important problem identified in the first questionnaire. However, none of its risk factors scored between the ten most important. The method chosen (questionnaires) has been partially successful in identifying the most relevant risk factors. It is believed that irrigation should be part of the initial HACCP plan because of its importance in sugarcane production. That is the reason why it has been surprising to identify other problems instead of irrigation as a major issue. The questionnaire method is clearly subjective, and therefore it is subject to misleading results if undertaken without the appropriate care.

Harvest has been identified as the most important Critical Control Point in the sugarcane production process. Most of the risk factors identified belong to this point in the process.

Once the plan has been put in place, it should remain open to modifications/updates as well as gradual additions of other hazards to make the methodology as complete as possible. It is important to start with a manageable amount of risk factors to focus the HACCP plan. Also, it should follow a continuous improvement cycle. This is to implement every new available piece of information gathered during one season, in order to make it as complete and updated as possible for the new season, and become a solid methodology that will allow control every hazard for productivity. It should decrease the likelihood of introducing hazards.

Besides the productivity hazards, the four most important technological problems constraining the adoption of PA have been identified. This should help better targeting the actual problems and designing more efficient strategies for farmers to engage on precision technologies. These risk factors are:

- Profit obtained with the technology:
  - Government regulations
  - Perception by the grower
- Cost of acquiring the technology
  - Farm size to face the cost
  - Uncertain return on investment

There was a problem with the response rate, it dropped to 56% by the third questionnaire and to 33% at the last questionnaire. It is not uncommon to see considerable drop in response rate in studies comprising a series of questionnaires (Hegelund and Sørensen 2007). It is considered to be explained by the duration of the study and anonymity of the panel. A good example can be seen in the third questionnaire, interview 1, where it’s openly asked not to be part of the panel anymore.

However, throughout the questionnaires there is a reasonably good degree of consensus in the scorings of both questionnaires 1 and 3. Some cases can be seen of clear disagreement that could be explained by poor communication about the tasks, the different backgrounds and the large distances between panel members, which implies, in some cases, very different issues.

Besides, the questionnaire method is a subjective method, which makes it difficult to score problems with the same mind set. For instance, it is remarkable that irrigation would not be selected, when off the questionnaires it is accepted as a major issue for sugarcane farms. This suggests that the way a problem is perceived could play an important role at the time of scoring them, so a generally accepted important issue could not be perceived as such. One reason could be that irrigation is already being taken care of as part of the basic management, and therefore there is no perception of its importance. However, if the same hazard would have been scored assuming that there is no previous management, it would be perceived as a critical hazard that could jeopardize the production.

This indicates that for a panel analysis to be fully successful it should have been important to interview experts and growers from a specific area. Also, from a small scale point of view is an indication that further steps on the implementation of a HACCP-like system must be farm specific, in order to successfully address the real problems. However, that would have misled in the goal of identifying problems that are common for the whole industry. Therefore, this confirms that the results found in this study can be considered valid from an industry-wide perspective and offer a good start point to address common issues, especially where research and development of technology is needed.

The ultimate goal is to identify which are the relevant technologies for the sugarcane industry that will allow monitoring the most important problems driving sugarcane production under Precision Agriculture, in order to control all possible hazards and apply corrective measures before it is too late and there is a productivity loss.

7. REFERENCES

(2009). Australian Sugarcane Annual. **13:** 32.

Aubry, C., M.-B. Galan, et al. (2005). "Garanties de qualité dans les exploitations agricoles: exemple de l'élaboration du référentiel Quali'Terre® en Picardie." Cahiers Agricultures **14**(3): 10.

Bakker, H. (1999). Sugar Cane Cultivation and Management.

Banhazi, T. and J. Black (2009). "Precision livestock farming: A suite of electronic systems to ensure the application of best practice management on livestock farms." Australian Journal of Multi-disciplinary Engineering **7**(1): 14.

Bramley, R. G. V. (2009). "Lessons from nearly 20 years of Precision Agriculture research, development, and adoption as a guide to its appropriate application." Crop and Pasture Science **60**(3): 197-217.

Campden BRI (2009). HACCP in agriculture: a practical guide.

Buresh, R. J. (2010). "Precision agriculture for small-scale farmers." Appropriate Technology **37**(4): 41-42.

Cook, S. E. and R. G. V. Bramley (1998). "Precision agriculture - opportunities, benefits and pitfalls of site-specific crop management in Australia." Australian Journal of Experimental Agriculture **38**: 753-763.

Cox, G., H. Harris, et al. (1997). Development and testing of a prototype yield mapping system. Proceedings of the Australian Society of Sugar Cane Technologists.

Department of Agriculture, F. a. F. (2012). Retrieved October 11, 2012, from http://www.daff.gov.au/agriculture-food/crops/sugar.

Fairfield Smith, H. (1938). "An Empirical Law Describing Heterogeneity in the Yields of Agricultural Crops." Journal of Agricultural Science **28**: 1-23.

FAO (1998). "Food Quality and Safety Systems - A Training Manual on Food Hygiene and the Hazard Analysis and Critical Control Point (HACCP) System." Retrieved 23 February 2012, from http://www.fao.org/docrep/W8088E/w8088e00.htm#Contents.

FAO, Ed. (2001). Hazard Analysis and Critical Control Point (HACCP), system and guidelines for its application. Annex to CAC/RCP 1- 1969, Rev. 3 (1997). Rome, Italy, The Secretariat of the Joint FAO/WHO Food Standards Programme.

FAO (2001). Manual on the Application of the HACCP System in Mycotoxin Prevention and Control. FAO/IAEA TRAINING AND REFERENCE CENTRE FOR FOOD AND PESTICIDE CONTROL. Rome, Italy. **Food and Nutrition Paper, n. 73.**

Galan, M. B., C. Aubry, et al. (2003). Farm Certification and the implementation of HACCP in agriculture: a cost/benefit analysis. Annual meeting of the American Agricultural Economics Association. Montreal, Canada.

Hegelund, L. and J. T. Sørensen (2007). "Developing a HACCP-like system for improving animal health and welfare in organic egg production – based on an expert panel analysis." Animal **1**(7): 8.

Horchner, P. M., D. Brett, et al. (2006). "HACCP-based approach to the derivation of an on-farm food safety program for the Australian red meat industry." Food Control **17**(7): 497-510.

Horchner, P. M. and A. M. Pointon (2011). "HACCP-based program for on-farm food safety for pig production in Australia." Food Control **22**(10): 1674-1688.

Leifert, C., K. Ball, et al. (2008). "Control of enteric pathogens in ready-to-eat vegetable crops in organic and 'low input' production systems: a HACCP-based approach." Journal of Applied Microbiology **105**: 931-950.

Lowenberg-DeBoer, J. (2003). Precision farming or convenience agriculture. Solutions for a better environment - Proceedings of the 11th Australian Agronomy Conference, Geelong, Vic, Australian Society of Agronomy.

Pardo, J. E., J. A. Peñaranda, et al. (2011). "Application of the hazard analysis and critical control point (HACCP)system on the mushroom processing line for fresh consumption." Italian Journal of Food Science **23**(2): 126-135.

Reid, R. L. (1981). A Manual of Australian Agriculture.

Runge, E. C. A. and F. M. Hons (1999). "Precision Agriculture — Development of a Hierarchy of Variables Influencing Crop Yields." Precision Agriculture **acsesspublicati**(precisionagric4a): 143-158.

Swinton, S. M. and J. Lowenberg-DeBoer (2001). Global adoption of precision agriculture technologies: who, when and why? 3rd European Conference on Precision Agriculture Agro Montpellier, Montpellier, France.

Toregeani-Mendes, K. A., C. C. Arroteia, et al. (2011). "Application of hazard analysis critical control points system for the control of aflatoxins in the Brazilian groundnut-based food industry." International Journal of Food Science and Technology **46**(12): 2611-2618.

8. ANNEX

8.1 Questionnaire 1. Interview 1

Interview 1 **Date:** 18/07/2012
Occupation: Expert-Researcher **Location:** Mackay

LIST OF PROBLEMS

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Soil pH	4	2
2	Soil type (texture)	2	5
3	Soil bulk density (compaction)	5	5
4	Soil CEC	3	2
5	Soil OM	4	2
6	Soil erosion/degradation (Wind/water erosion)	3	2
7	contamination (pesticides/herbicides/fertilization)	1	5
8	Soil salinization	5	3
9	ASS soils	4	2
10	Soil depth	1	1
11	Pests	4	5
12	Diseases	2	5
13	Weeds	4	4
14	Water availability	5	5
15	Water quality	5	3
16	Irrigation system	3	3
17	Drainage/Waterlogging	4	2
18	Runoff/leaching	5	5
19	Topography	3	2
20	Fertilization type	1	1
21	Fertilization method	3	2
22	Fertilization frequency	5	5
23	Harvesting date	4	5
24	Harvest green cane / burnt cane	3	2
25	Variety selection	5	5
26	Crop rotation	5	4
27	Ratoon number	5	5
28	Planting density	5	5
29	Planting costs	5	5
30	Distance to rivers/sea/wetlands/forests	4	3
31	Noise	2	1
32	Air pollution	1	2
33	Disposal of used materials/Waste management	2	4
34	Rainfall	4	3
35	Temperature	1	2

36	Hail	1	1
37	Solar radiation	1	1
38	Proper machinery	4	3
39	Fallow/Break crop	4	4
40	Manager's tools	4	3
41	Manager's knowledge	5	3
42	Harvester ground job	5	4
43	Harvester chopper losses	4	5
44	Harvester forward speed	4	3
45	Harvesting costs	4	4
46	Harvester extractor losses	5	5
47	Performance of chemical application	4	3

LIST OF TECHNOLOGICAL PROBLEMS

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Obsolescence	3	4
2	Compatibility	5	5
3	Knowledge of what equipment can do	4	4
4	Knowledge of what you do with the answer/output	4	4
5	Suitability of equipment (specificity/sensitivity for the actual crop)	5	5
6	Support	5	4
7	Cost	4	4
8	Yield monitors	5	5
9	Profit or other benefits (environmental/legal)	5	5

8.2 Questionnaire 1. Interview 2

Interview 2 **Date:** 30/07/2012
Occupation: Grower **Location:** Bundaberg District

LIST OF PROBLEMS

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Soil pH	4	3
2	Soil type (texture)		
3	Soil bulk density (compaction)	3	3
4	Soil Cation Exchange Capacity	4	4
5	Soil Organic Matter	4	4
6	Soil erosion/degradation (Wind/water erosion)	1	1
7	Contamination of soil (pesticides/herbicides/fertilization)	3	2
8	Soil salinization	4	2
9	Intoxication of plants (pesticides/herbicides)	4	1
10	Contamination of environment	2	2
11	Acid Sulphate Soils	4	2
12	Soil depth	3	2
13	Pests	4	4
14	Diseases	5	3
15	Weeds	4	4
16	Water availability	5	3
17	Water quality	4	3
18	Irrigation system	4	2
19	Drainage/Waterlogging	5	2
20	Runoff/leaching/loss of nutrients/Groundwater contamin.	3	3
21	Topography	3	3
22	Fertilization/Fertilization type	4	2
23	Harvesting date	1	1
24	Harvest green cane / burnt cane	1	1
25	Variety selection	5	5
26	Crop rotation	4	3
27	Ratoon number	3	2
28	Planting density	3	2
29	Planting costs	2	3
30	Planting row spacing	1	1
31	Loss of contaminants		
32	Distance to rivers/sea/wetlands/forests	3	3
33	Presence of endangered species	2	1
34	Protected areas	3	3
35	Noise	3	4

36	Air pollution	2	4
37	Disposal of used materials/Waste management	2	1
38	Rainfall	3	4
39	Temperature	3	4
40	Hail	1	1
41	Solar radiation	2	1
42	Proper machinery	4	3
43	Fallow	5	5
44	Technologies	4	2
45	Manager's tools	4	4
46	Manager's knowledge	5	3
47	Harvester ground job	4	3
48	Harvester chopper losses	3	4
49	Harvester forward speed	4	4
50	Harvesting costs	3	3
51	Harvester’s extractor losses	3	3
52	Performance of chemical application	3	4
53	Natural extreme weather (dry)	4	2
54	Natural extreme weather (wet)	5	1
55	Cyclones	4	1

LIST OF TECHNOLOGICAL PROBLEMS

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Obsolescence	5	4
2	Compatibility	5	4
3	Knowledge of what equipment can do	4	4
4	Knowledge of what you do with the answer/output	5	5
5	Suitability of equipment (specificity/sensitivity for the actual crop)	4	5
6	Support	5	5
7	Cost	3	3
8	Yield monitors	4	3
9	Yield/Cost/Profit or other benefit (legal, environmental…)	3	4

8.3 Questionnaire 1. Interview 3

Interview 3
Position: Grower/Expert

Date: 1/08/2012
Location: Bundaberg District

LIST OF PROBLEMS

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Soil pH	3	2
2	Soil type (texture)	3	4
3	Soil structure	5	4
4	Soil bulk density (compaction)	2	3
5	Soil CEC	5	2
6	Soil OM	5	2
7	Soil erosion/degradation (Wind/water erosion)	1	1
8	contamination (pesticides/herbicides/fertilization)	1	1
9	Soil salinization	5	2
10	Intoxication (pesticides/herbicides)	1	1
11	ASS soils		
12	Soil depth	5	4
13	Pests	1	1
14	Diseases	1	1
15	Weeds	4	3
16	Water availability	4	1
17	Water quality	3	1
18	Irrigation system	4	4
19	Drainage/Waterlogging	5	5
20	Runoff/leaching	2	2
21	Topography	4	3
22	Fertilization/Fertilization type	1	3
23	Harvesting date	4	4
24	Harvest green cane / burnt cane	4	4
25	Variety selection	4	3
26	Crop rotation	5	2
27	Ratoon number	3	3
28	Planting density	1	4
29	Groundwater contamination	2	2
30	Loss of nutrients	3	4
31	Loss of contaminants	1	1
32	Distance to rivers/sea/wetlands/forests	1	1
33	Presence of endangered species	1	1
34	Protected areas	1	1
35	Noise	1	1

36	Air pollution	1	3
37	Disposal of used materials/Waste management	1	1
38	Rainfall	5	4
39	Temperature	2	3
40	Hail	1	1
41	Solar radiation	3	3
42	Proper machinery	5	4
43	Fallow	4	2
44	Technologies	4	3
45	Manager's tools	5	5
46	Manager's knowledge	3	2

LIST OF TECHNOLOGICAL PROBLEMS

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Obsolescence	5	2
2	Compatibility	5	1
3	Knowledge of what equipment can do	4	3
4	Knowledge of what you do with the answer/output	2	2
5	Suitability of equipment (specificity/sensitivity for the actual crop)	3	3
6	Support	5	3
7	Cost	3	3
8	Yield monitors	1	1

8.4 Questionnaire 1. Interview 4

Interview 4
Occupation: Expert/Researcher

Date: 1/08/2012
Location: Bundaberg District

LIST OF PROBLEMS

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Soil pH		
2	Soil type (texture)		
3	Soil bulk density (compaction)	5	4
4	Soil Cation Exchange Capacity		
5	Soil Organic Matter	4	3
6	Soil erosion/degradation (Wind/water erosion)		
7	Contamination of soil (pesticides/herbicides/fertilization)		
8	Soil salinization		
9	Intoxication of plants (pesticides/herbicides)		
10	Contamination of environment		
11	Acid Sulphate Soils		
12	Soil depth		
13	Pests	4	4
14	Diseases	3	3
15	Weeds	4	4
16	Water availability		
17	Water quality		
18	Irrigation system		
19	Drainage/Waterlogging		
20	Runoff/leaching/loss of nutrients/Groundwater contamin.	3	3
21	Topography		
22	Fertilization/Fertilization type		
23	Harvesting date		
24	Harvest green cane / burnt cane		
25	Variety selection		
26	Crop rotation		
27	Ratoon number		
28	Planting (density, row spacing, costs, establishment)	4	3
29	Loss of contaminants		
30	Distance to rivers/sea/wetlands/forests		
31	Presence of endangered species		
32	Protected areas		
33	Noise		
34	Air pollution		
35	Disposal of used materials/Waste management		

36	Rainfall	3	3
37	Temperature		
38	Hail		
39	Solar radiation		
40	Proper machinery		
41	Fallow		
42	Technologies		
43	Manager's tools		
44	Manager's knowledge		
45	Harvesting losses (ground job, chopper losses, forward speed, extractor losses,…)	4	4
46	Harvesting costs	3	4
47	Performance of chemical application		
48	Natural calamities (cyclones,excessive rainfall, drought,…)		

LIST OF TECHNOLOGICAL PROBLEMS

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Obsolescence		
2	Compatibility	3	5
3	Knowledge of what equipment can do		
4	Knowledge of what you do with the answer/output	4	4
5	Suitability of equipment (specificity/sensitivity for the actual crop)		
6	Support	4	4
7	Cost		
8	Yield monitors	5	4
9	Yield/Cost/Profit or other benefit (legal, environmental,…)		

8.5 Questionnaire 1. Interview 5

Interview 5
Occupation: Manager of HCPSC

Date: 17/08/2012
Location: Herbert-Ingham

LIST OF PROBLEMS

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Soil pH	4	4
2	Soil type (texture)	3	3
3	Soil bulk density (compaction)	4	4
4	Soil Cation Exchange Capacity	3	3
5	Soil Organic Matter	3	3
6	Soil erosion/degradation (Wind/water erosion)	1	1
7	Contamination of soil (pesticides/herbicides/fertilization)	2	1
8	Soil salinization	4	1
9	Intoxication of plants (pesticides/herbicides)	1	1
10	Contamination of environment	3	3
11	Acid Sulphate Soils	4	1
12	Soil depth	4	3
13	Pests	4	5
14	Diseases	4	4
15	Weeds	4	3
16	Water availability	2	3
17	Water quality	1	1
18	Irrigation system	2	2
19	Drainage/Waterlogging	5	4
20	Runoff/leaching/loss of nutrients/Groundwater contamin.	3	3
21	Topography	2	2
22	Fertilization/Fertilization type	2	2
23	Harvesting date	4	3
24	Harvest green cane / burnt cane	1	1
25	Variety selection	3	3
26	Crop rotation	1	1
27	Ratoon number	4	4
28	Planting (density, row spacing, costs, establishment)	2	2
29	Loss of contaminants	2	2
30	Distance to rivers/sea/wetlands/forests	1	1
31	Presence of endangered species	3	4
32	Protected areas	3	3
33	Noise	2	1
34	Air pollution	2	1
35	Disposal of used materials/Waste management	1	1

36	Rainfall	4	4
37	Temperature	2	2
38	Hail	1	1
39	Solar radiation	4	3
40	Proper machinery	3	3
41	Fallow	4	3
42	Technologies	4	3
43	Manager's tools	3	3
44	Manager's knowledge	4	4
45	Harvesting losses (ground job, chopper losses, forward speed, extractor losses,…)	4	3
46	Harvesting costs	5	5
47	Performance of chemical application	3	3
48	Natural calamities (cyclones,excessive rainfall, drought,…)	5	3

LIST OF TECHNOLOGICAL PROBLEMS

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Obsolescence	4	4
2	Compatibility	5	4
3	Knowledge of what equipment can do	5	4
4	Knowledge of what you do with the answer/output	4	4
5	Suitability of equipment (specificity/sensitivity for the actual crop)	2	2
6	Support	3	3
7	Cost	4	4
8	Yield monitors	3	2
9	Yield/Cost/Profit or other benefit (legal, environmental…)	4	4

8.6 Questionnaire 1. Interview 6

Interview 6
Occupation: GIS and Precision Ag Co-ordinator

Date: 17/08/2012
Location: Herbert-Ingham

LIST OF PROBLEMS

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Soil pH	4	3
2	Soil type (texture)	3	3
3	Soil bulk density (compaction)	4	4
4	Soil Cation Exchange Capacity	3	3
5	Soil Organic Matter	3	3
6	Soil erosion/degradation (Wind/water erosion)	1	1
7	Contamination of soil (pesticides/herbicides/fertilization)	2	1
8	Soil salinization	4	1
9	Intoxication of plants (pesticides/herbicides)	2	1
10	Contamination of environment	2	1
11	Acid Sulphate Soils	4	1
12	Soil depth	3	3
13	Pests	4	4
14	Diseases	4	4
15	Weeds	3	2
16	Water availability	2	3
17	Water quality	1	1
18	Irrigation system	2	2
19	Drainage/Waterlogging	4	3
20	Runoff/leaching/loss of nutrients/Groundwater contamin.	3	3
21	Topography	2	2
22	Fertilization/Fertilization type	3	3
23	Harvesting date	3	3
24	Harvest green cane / burnt cane	1	1
25	Variety selection	4	4
26	Crop rotation	4	4
27	Ratoon number	4	4
28	Planting (density, row spacing, costs, establishment)	4	3
29	Loss of contaminants	3	3
30	Distance to rivers/sea/wetlands/forests	1	1
31	Presence of endangered species	3	3
32	Protected areas	3	3
33	Noise	2	2
34	Air pollution	1	1
35	Disposal of used materials/Waste management	3	3

36	Rainfall	4	3
37	Temperature	2	2
38	Hail	1	1
39	Solar radiation	4	1
40	Proper machinery	5	5
41	Fallow	4	3
42	Technologies	4	3
43	Manager's tools	4	4
44	Manager's knowledge	4	4
45	Harvesting losses (ground job, chopper losses, forward speed, extractor losses,…)	5	5
46	Harvesting costs	5	5
47	Performance of chemical application	4	3
48	Natural calamities (cyclones,excessive rainfall, drought,…)	5	3

LIST OF TECHNOLOGICAL PROBLEMS

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Obsolescence	4	4
2	Compatibility	4	4
3	Knowledge of what equipment can do	4	4
4	Knowledge of what you do with the answer/output	4	4
5	Suitability of equipment (specificity/sensitivity for the actual crop)	4	4
6	Support	3	3
7	Cost	4	4
8	Yield monitors	3	2
9	Yield/Cost/Profit or other benefit (legal, environmental…)	4	4

8.7 Questionnaire 1. Interview 7

Interview 7 **Date:** 23/08/2012
Occupation: Farm Manager **Location:** Ingham

LIST OF PROBLEMS

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Soil pH	3	1
2	Soil type (texture)	1	1
3	Soil bulk density (compaction)	3	2
4	Soil Cation Exchange Capacity	1	1
5	Soil Organic Matter	3	3
6	Soil erosion/degradation (Wind/water erosion)	1	1
7	Contamination of soil (pesticides/herbicides/fertilization)	1	1
8	Soil salinization	1	1
9	Intoxication of plants (pesticides/herbicides)	1	1
10	Contamination of environment	1	1
11	Acid Sulphate Soils	3	2
12	Soil depth	3	3
13	Pests	3	3
14	Diseases	4	3
15	Weeds	1	1
16	Water availability	1	1
17	Water quality	1	1
18	Irrigation system	1	1
19	Drainage/Waterlogging	1	1
20	Runoff/leaching/loss of nutrients/Groundwater contamin.	1	1
21	Topography	1	1
22	Fertilization/Fertilization type	1	1
23	Harvesting date	3	3
24	Harvest green cane / burnt cane	1	1
25	Variety selection	4	4
26	Crop rotation	4	4
27	Ratoon number	3	3
28	Planting (density, row spacing, costs, establishment)	1	1
29	Loss of contaminants	1	1
30	Distance to rivers/sea/wetlands/forests	1	1
31	Presence of endangered species	1	1
32	Protected areas	2	2
33	Noise	1	1
34	Air pollution	1	1
35	Disposal of used materials/Waste management	2	2

36	Rainfall	4	4
37	Temperature	1	1
38	Hail	1	1
39	Solar radiation	1	1
40	Proper machinery	1	1
41	Fallow	3	3
42	Technologies	3	3
43	Manager's tools	3	3
44	Manager's knowledge	4	4
45	Harvesting losses (ground job, chopper losses, forward speed, extractor losses,…)	5	5
46	Harvesting costs	5	5
47	Performance of chemical application	4	4
48	Natural calamities (cyclones,excessive rainfall, drought,…)	4	4

LIST OF TECHNOLOGICAL PROBLEMS

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Obsolescence	2	2
2	Compatibility	4	4
3	Knowledge of what equipment can do	3	3
4	Knowledge of what you do with the answer/output	3	3
5	Suitability of equipment (specificity/sensitivity for the actual crop)	2	2
6	Support	3	3
7	Cost	4	4
8	Yield monitors	3	3
9	Yield/Cost/Profit or other benefit (legal, environmental…)	3	3

8.8 Questionnaire 1. Interview 8

Interview 8
Occupation: Research assistant

Date: 24/08/2012
Location: Ingham

LIST OF PROBLEMS

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Soil pH	2	5
2	Soil type (texture)	3	3
3	Soil bulk density (compaction)	4	4
4	Soil Cation Exchange Capacity	3	2
5	Soil Organic Matter	4	4
6	Soil erosion/degradation (Wind/water erosion)	2	1
7	Contamination of soil (pesticides/herbicides/fertilization)	3	3
8	Soil salinization	2	2
9	Intoxication of plants (pesticides/herbicides)	2	2
10	Contamination of environment	2	2
11	Acid Sulphate Soils	3	2
12	Soil depth	2	2
13	Pests	4	4
14	Diseases	4	4
15	Weeds	4	4
16	Water availability	3	4
17	Water quality	2	2
18	Irrigation system	2	2
19	Drainage/Waterlogging	4	5
20	Runoff/leaching/loss of nutrients/Groundwater contamin.	3	4
21	Topography	2	2
22	Fertilization/Fertilization type	3	3
23	Harvesting date	4	4
24	Harvest green cane / burnt cane	3	3
25	Variety selection	3	3
26	Crop rotation	3	3
27	Ratoon number	3	3
28	Planting (density, row spacing, costs, establishment)	2	2
29	Loss of contaminants	3	3
30	Distance to rivers/sea/wetlands/forests	3	3
31	Presence of endangered species	3	3
32	Protected areas	3	3
33	Noise	2	2
34	Air pollution	2	2
35	Disposal of used materials/Waste management	2	2

36	Rainfall	3	3
37	Temperature	2	2
38	Hail	1	1
39	Solar radiation	4	3
40	Proper machinery	3	3
41	Fallow	3	3
42	Technologies	3	3
43	Manager's tools	3	3
44	Manager's knowledge	3	3
45	Harvesting losses (ground job, chopper losses, forward speed, extractor losses,…)	4	4
46	Harvesting costs	4	4
47	Performance of chemical application	3	3
48	Natural calamities (cyclones,excessive rainfall, drought,…)	3	3

LIST OF TECHNOLOGICAL PROBLEMS

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Obsolescence	4	3
2	Compatibility	5	4
3	Knowledge of what equipment can do	4	3
4	Knowledge of what you do with the answer/output	5	4
5	Suitability of equipment (specificity/sensitivity for the actual crop)	3	3
6	Support	3	3
7	Cost	5	5
8	Yield monitors	4	3
9	Yield/Cost/Profit or other benefit (legal, environmental…)	4	4

8.9 Questionnaire 1. Interview 9

Interview 9 **Date:** 30/08/2012
Occupation: Grower **Location:** Ayr

LIST OF PROBLEMS

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Soil pH	2	2
2	Soil type (texture)	2	1
3	Soil bulk density (compaction)	3	4
4	Soil Cation Exchange Capacity	3	2
5	Soil Organic Matter	2	3
6	Soil erosion/degradation (Wind/water erosion)	1	2
7	Contamination of soil (pesticides/herbicides/fertilization)	1	3
8	Soil salinization	3	3
9	Intoxication of plants (pesticides/herbicides)	1	2
10	Contamination of environment	2	4
11	Acid Sulphate Soils	1	1
12	Soil depth	2	1
13	Pests	3	4
14	Diseases	2	4
15	Weeds	4	5
16	Water availability	3	3
17	Water quality	3	3
18	Irrigation system	4	5
19	Drainage/Waterlogging	3	3
20	Runoff/leaching/loss of nutrients/Groundwater contamin.	4	4
21	Topography	2	2
22	Fertilization/Fertilization type	4	5
23	Harvesting date	4	4
24	Harvest green cane / burnt cane	4	4
25	Variety selection	3	4
26	Crop rotation	2	3
27	Ratoon number	2	3
28	Planting (density, row spacing, costs, establishment)	4	4
29	Loss of contaminants	4	4
30	Distance to rivers/sea/wetlands/forests	2	2
31	Presence of endangered species	1	1
32	Protected areas	1	1
33	Noise	1	1
34	Air pollution	1	1
35	Disposal of used materials/Waste management	1	2

36	Rainfall	4	5
37	Temperature	2	3
38	Hail	1	1
39	Solar radiation	2	5
40	Proper machinery	3	4
41	Fallow	3	5
42	Technologies	4	4
43	Manager's tools	2	3
44	Manager's knowledge	3	5
45	Harvesting losses (ground job, chopper losses, forward speed, extractor losses,…)	4	4
46	Harvesting costs	4	4
47	Performance of chemical application	3	5
48	Natural calamities (cyclones,excessive rainfall, drought,…)	3	4

LIST OF TECHNOLOGICAL PROBLEMS

nr	*Problem*	*Severity (1-5)*	*Frequency (1-5)*
1	Obsolescence	3	3
2	Compatibility	3	2
3	Knowledge of what equipment can do	3	1
4	Knowledge of what you do with the answer/output	4	3
5	Suitability of equipment (specificity/sensitivity for the actual crop)	4	4
6	Support	4	3
7	Cost	5	2
8	Yield monitors	5	4
9	Yield/Cost/Profit or other benefit (legal, environmental…)	5	4

8.10 Questionnaire 1. Results

			Interview									Severity				Frequency			
nr	*Problem*		*ONE*	*TWO*	*THREE*	*FOUR*	*FIVE*	*SIX*	*SEVEN*	*EIGHT*	*NINE*	*n*	*Median*	*Avg*	*IQR*	*n*	*Median*	*Avg*	*IQR*
1	Soil pH	Severity	4	4	3	2	4	-	2	4	3	8	3,5	3,25	1,25	8	2,5	2,50	1
		Frequency	2	3	2	3	3	-	2	4	1								
2	Soil type (texture)	Severity	2	-	3	3	3	-	2	3	1	7	3	2,43	1	7	3	2,86	1,5
		Frequency	5	-	4	3	3	-	1	3	1								
3	Soil bulk density (compaction)	Severity	5	3	2	4	4	5	3	4	3	9	4	3,67	1	9	4	3,67	1
		Frequency	5	3	3	4	4	4	4	4	2								
4	Soil Cation Exchange Capacity	Severity	3	4	5	3	3	-	3	3	1	8	3	3,13	0,25	8	2	2,38	1
		Frequency	2	4	2	2	3	-	2	3	1								
5	Low soil Organic Matter	Severity	4	4	5	4	3	4	2	3	3	9	4	3,56	1	9	3	3	0
		Frequency	2	4	2	4	3	3	3	3	3								
6	Soil erosion/ degradation	Severity	3	1	1	2	1	-	1	1	1	8	1	1,38	0,25	8	1	1,25	0,25
		Frequency	2	1	1	1	1	-	2	1	1								
7	Contamination of soil (pesticides/ herbicides)	Severity	1	3	1	3	2	-	1	2	1	8	1,5	1,75	1,25	8	1,5	2,13	2
		Frequency	5	2	1	3	1	-	3	1	1								
8	Soil salinization	Severity	5	4	5	2	4	-	3	4	1	8	4	3,50	1,5	8	2	1,88	1,25
		Frequency	3	2	2	2	1	-	3	1	1								
9	Intoxication of plants (pesticides/ herbicides)	Severity	-	4	1	2	2	-	1	1	1	7	1	1,71	1	7	1	1,29	0,5
		Frequency	-	1	1	2	1	-	2	1	1								
10	Contamination of environment	Severity	-	2	-	2	2	-	2	3	1	6	2	2	0	6	2	2,17	1,5
		Frequency	-	2	-	2	1	-	4	3	1								
11	Acid Sulphate Soils	Severity	4	4	-	3	4	-	1	4	3	7	4	3,29	1	7	2	1,57	1
		Frequency	2	2	-	2	1	-	1	1	2								

			Interview									Severity				Frequency			
nr	Problem		ONE	TWO	THREE	FOUR	FIVE	SIX	SEVEN	EIGHT	NINE	n	Median	Avg	IQR	n	Median	Avg	IQR
12	Shallow soil	Severity	1	3	5	2	3	-	2	4	3	8	3	2,88	1,25	8	2,5	2,38	1,25
		Frequency	1	2	4	2	3	-	1	3	3								
13	Pests	Severity	4	4	1	4	4	4	3	4	3	9	4	3,44	1	9	4	3,78	0
		Frequency	5	4	1	4	4	4	4	5	3								
14	Diseases	Severity	2	5	1	4	4	3	2	4	4	9	4	3,22	2	9	4	3,44	1
		Frequency	5	3	1	4	4	3	4	4	3								
15	Weeds	Severity	4	4	4	3	3	4	4	4	1	9	4	3,44	1	9	4	3,33	1
		Frequency	4	4	3	4	2	4	5	3	1								
16	Water availability	Severity	5	5	4	3	2	-	3	2	1	8	3	3,13	2,25	8	3	2,88	0,75
		Frequency	5	3	1	4	3	-	3	3	1								
17	Water quality	Severity	5	4	3	2	1	-	3	1	1	8	2,5	2,50	2,25	8	1,5	1,88	2
		Frequency	3	3	1	2	1	-	3	1	1								
18	Irrigation system	Severity	3	4	4	2	2	-	4	2	1	8	2,5	2,75	2	8	2	2,63	1,25
		Frequency	3	2	4	2	2	-	5	2	1								
19	Drainage/Waterlogging	Severity	4	5	5	4	4	-	3	5	1	8	4	3,88	1,25	8	3	3,13	2,25
		Frequency	2	2	5	5	3	-	3	4	1								
20	Runoff/ leaching/ loss of nutrients	Severity	5	3	2	3	3	3	4	3	1	9	3	3	0	9	3	3,11	1
		Frequency	5	3	2	4	3	3	4	3	1								
21	Topography	Severity	3	3	4	2	2	-	2	2	1	8	2	2,38	1	8	2	2,13	0,25
		Frequency	2	3	3	2	2	-	2	2	1								
22	Fertilization/Fertilization type	Severity	1	4	1	3	3	-	4	2	1	8	2,5	2,38	2,25	8	2,5	2,50	1,25
		Frequency	1	2	3	3	3	-	5	2	1								
23	Harvesting date	Severity	4	1	4	4	3	-	4	4	3	8	4	3,38	1	8	3,5	3,38	1
		Frequency	5	1	4	4	3	-	4	3	3								

			Interview									Severity				Frequency			
nr	*Problem*		*ONE*	*TWO*	*THREE*	*FOUR*	*FIVE*	*SIX*	*SEVEN*	*EIGHT*	*NINE*	*n*	*Median*	*Avg*	*IQR*	*n*	*Median*	*Avg*	*IQR*
24	Harvest green cane / burnt cane	Severity	3	1	4	3	1	-	4	1	1	8	2	2,25	2,25	8	1,5	2,13	2,25
		Frequency	2	1	4	3	1	-	4	1	1								
25	Variety selection	Severity	5	5	4	3	4	-	3	3	4	8	4	3,88	1,25	8	4	3,88	1,25
		Frequency	5	5	3	3	4	-	4	3	4								
26	Crop rotation	Severity	5	4	5	3	4	-	2	1	4	8	4	3,50	1,5	8	3	3	1,25
		Frequency	4	3	2	3	4	-	3	1	4								
27	Ratoon number	Severity	5	3	3	3	4	-	2	4	3	8	3	3,38	1	8	3	3,38	1
		Frequency	5	2	3	3	4	-	3	4	3								
28	Planting (density, row spacing, costs…)	Severity	5	2	1	2	4	4	4	2	1	9	2	2,78	2	9	3	2,89	2
		Frequency	5	2	4	2	3	3	4	2	1								
29	Loss of contaminants	Severity	-	-	1	3	3	-	4	2	1	6	2,5	2,33	1,75	6	2,5	2,33	1,75
		Frequency	-	-	1	3	3	-	4	2	1								
30	Distance to rivers/sea/wetlands/forests	Severity	4	3	1	3	1	-	2	1	1	8	1,5	2	2	8	1,5	1,88	2
		Frequency	3	3	1	3	1	-	2	1	1								
31	Presence of endangered species	Severity	-	2	1	3	3	-	1	3	1	7	2	2	2	7	1	2	2
		Frequency	-	1	1	3	3	-	1	4	1								
32	Protected areas	Severity	-	3	1	3	3	-	1	3	2	7	3	2,29	1,5	7	3	2,29	1,5
		Frequency	-	3	1	3	3	-	1	3	2								
33	Noise	Severity	2	3	1	2	2	-	1	2	1	8	2	1,75	1	8	1	1,63	1
		Frequency	1	4	1	2	2	-	1	1	1								
34	Air pollution	Severity	1	2	1	2	1	-	1	2	1	8	1	1,38	1	8	1,5	1,88	1,25
		Frequency	2	4	3	2	1	-	1	1	1								
35	Disposal of used materials/Waste management	Severity	2	2	1	2	3	-	1	1	2	8	2	1,75	1	8	2	2	1,25
		Frequency	4	1	1	2	3	-	2	1	2								

			Interview									Severity				Frequency			
nr	*Problem*		*ONE*	*TWO*	*THREE*	*FOUR*	*FIVE*	*SIX*	*SEVEN*	*EIGHT*	*NINE*	*n*	*Median*	*Avg*	*IQR*	*n*	*Median*	*Avg*	*IQR*
36	Rainfall	Severity	4	3	5	3	4	3	4	4	4	9	4	3,78	1	9	4	3,67	1
		Frequency	3	4	4	3	3	3	5	4	4								
37	Temperature	Severity	1	3	2	2	2	-	2	2	1	8	2	1,88	0,25	8	2	2,38	1
		Frequency	2	4	3	2	2	-	3	2	1								
38	Hail	Severity	1	1	1	1	1	-	1	1	1	8	1	1	0	8	1	1,00	0
		Frequency	1	1	1	1	1	-	1	1	1								
39	Solar radiation	Severity	1	2	3	4	4	-	2	4	1	8	2,5	2,63	2,25	8	2	2,25	2
		Frequency	1	1	3	3	1	-	5	3	1								
40	Proper machinery	Severity	4	4	5	3	5	-	3	3	1	8	3,5	3,50	1,25	8	3	3,25	1
		Frequency	3	3	4	3	5	-	4	3	1								
41	Fallow	Severity	4	5	4	3	4	-	3	4	3	8	4	3,75	1	8	3	3,50	1,25
		Frequency	4	5	2	3	3	-	5	3	3								
42	Technologies	Severity	-	4	-	3	4	-	4	4	3	6	4	3,67	0,75	6	3	3,00	0
		Frequency	-	2	-	3	3	-	4	3	3								
43	Manager's tools	Severity	4	4	5	3	4	-	2	3	3	8	3,5	3,50	1	8	3	3,50	1
		Frequency	3	4	5	3	4	-	3	3	3								
44	Manager's knowledge	Severity	5	5	3	3	4	-	3	4	4	8	4	3,88	1,25	8	3,5	3,50	1
		Frequency	3	3	2	3	4	-	5	4	4								
45	Harvesting losses (chopper losses, extractor losses)	Severity	4	4	-	4	5	4	4	4	5	8	4	4,25	0,25	8	4	4,13	0,25
		Frequency	4	4	-	4	5	4	4	3	5								
46	Harvesting costs	Severity	4	3	-	4	5	3	4	5	5	8	4	4,13	1,25	8	4	4,25	1
		Frequency	4	3		4	5	4	4	5	5								
47	Performance of chemical application	Severity	4	3	-	3	4	-	3	3	4	7	3	3,43	1	7	3	3,57	1
		Frequency	3	4	-	3	3	-	5	3	4								
48	Natural calamities (cyclones,…)	Severity	-	4	-	3	5	-	3	5	4	6	4	4	1,5	6	3	3,00	0,75
		Frequency	-	1	-	3	3	-	4	3	4								

			Interview									Severity				Frequency			
nr	*Problem*		*ONE*	*TWO*	*THREE*	*FOUR*	*FIVE*	*SIX*	*SEVEN*	*EIGHT*	*NINE*	*n*	*Median*	*Avg*	*IQR*	*n*	*Median*	*Avg*	*IQR*
1	Obsolescence	Severity	3	5	5	4	4	-	3	4	2	8	4	3,75	1,25	8	3,5	3,25	1,25
		Frequency	4	4	2	3	4	-	3	4	2								
2	Compatibility	Severity	5	5	5	5	4	3	3	5	4	9	5	4,33	1	9	4	3,67	0
		Frequency	5	4	1	4	4	5	2	4	4								
3	Knowledge of what equipment can do	Severity	4	4	4	4	4	-	3	5	3	8	4	3,88	0,25	8	3,5	3,25	1
		Frequency	4	4	3	3	4	-	1	4	3								
4	Knowledge of what you do with the answer/output	Severity	4	5	2	5	4	4	4	4	3	9	4	3,89	0	9	4	3,67	1
		Frequency	4	5	2	4	4	4	3	4	3								
5	Suitability of equipment (specificity/sensitivity for the actual crop)	Severity	5	4	3	3	4	-	4	2	2	8	3,5	3,38	1,25	8	3,5	3,50	1,5
		Frequency	5	5	3	3	4	-	4	2	2								
6	Support	Severity	5	5	5	3	3	4	4	3	3	9	4	3,89	2	9	3	3,44	1
		Frequency	4	5	3	3	3	4	3	3	3								
7	Cost	Severity	4	3	3	5	4	-	5	4	4	8	4	4	0,5	8	4	3,63	1
		Frequency	4	3	3	5	4	-	2	4	4								
8	Yield monitors	Severity	5	4	1	4	3	5	5	3	3	9	4	3,67	2	9	3	3	2
		Frequency	5	3	1	3	2	4	4	2	3								
9	Yield/Cost/Profit or other benefit (legal, environmental,...)	Severity	5	3	-	4	4	-	5	4	3	7	4	4	1	7	4	4	0
		Frequency	5	4	-	4	4	-	4	4	3								

8.11 Questionnaire 2. Interview 1

Interview 1 **Date:** 18/07/2012
Occupation: Expert-Researcher **Location:** Mackay

MOST IMPORTANT PROBLEMS

nr	*Problem*	*Risk factors*
14	Water availability	- Politics - Drought - Salinity ingression
25	Variety	- Grower Knowledge - Availability of decision tools - Continued supply of varieties - Cost. Propagation time - Risk management
18	Runoff/Nutrient loss	- Water/nutrient application mgmt - Water/nutrient application technologies - Measurement technologies off-farm impacts - Cost of application/Cost of inputs
27	Ratoon number	- Yield decline - Stool loss - Cost of planting - Cost of replanting (in-fill planting)
28	Plant density	- Cost of replanting (in-fill planting) - Availability of growers time
29	Planting costs	- Cost of planting
3	Compaction	- Row spacing - Axle load - Controlled traffic - Soil moisture - Soil type
46	Harvesting losses	- Operator knowledge - Operator information feedback systems - Machine design
11	Pests	- Low biodiversity/pest enemies - Pest vectors/pressure - Existence of control mechanisms - Potential insect resistance
23	Harvesting date	- variety - time of harvesting - likelihood of rain - social issues

MOST IMPORTANT TECHNOLOGICAL PROBLEMS

nr	*Problem*	*Risk factors*
	Profit/Other benefits	- Perception by the grower - Information feedback
	Compatibility	- ISO standards - Incompatibility
	Suitability	- Ease of use - Not suitable for actual crop
	Yield monitors	- Currently in development - Huge potential for feedback information to growers

COMMENTS

A. Australia grow cane on around 200 of it's 280 soil types. This is managed mostly through variety (produced by BSES) and associated agronomy.
B. Australian cane has very few pests except for cane grub. There is now a chemical to treat these (Suscon). Other than that there is soldier fly and a few other also minor pests. Peter Sampson, BSES Mackay Entomologist is a good source for pest information.
C. Chlorotic streak, smut and a host of other diseases exist. Again these are managed by breeding resistant varieties. Soil pachymetra (sp?) is a problem that is managed via variety rotation (ie choosing resistant varieties after a low resistant variety or a banana crop).
D. Mostly tropical ag with steep topography. Management of the problem is required.
E. Region and soil type specific.

8.12 Questionnaire 2. Interview 2

Interview 2 **Date:** 30/07/2012
Occupation: Grower **Location:** Bundaberg District

MOST IMPORTANT PROBLEMS

nr	*Problem*	*Risk factors*
25	Variety Selection	- Disease resistance - New varieties unproven on farm
43	Fallow	- Pests hosted by fallow crop - Chemical incompatibility with cane
4	Soil Cation Exchange Capacity	- Lock up of nutrients
5	Soil Organic Matter	- Retention of applied nutrients - Friability
13	Pests	- Yield suppression - Reduced nutrient efficiency - Ratooning reduction
15	Weeds	- Yield suppression - Nutrient syphoning
45	Manager's tools	- Not correct for problem applied to - Not current - Restricted to current tools
49	Harv. Forward speed	- Stool disease susceptibility - CCS decrease due to extraneous matter - Stool sent to mill
14	Diseases	- Yield suppression - Reduced nutrient efficiency - Ratooning reduction
16	Water availability	- Reduced nutrient efficiency - Quality - If low, what to irrigate, plant, ratoon or high production
46	Managers knowledge	- Not current - Can be one dimensional - Doesn't know what he doesn't know

MOST IMPORTANT TECHNOLOGICAL PROBLEMS

nr	*Problem*	*Risk factors*
1	Obsolescence	- Equipment becoming orphaned - If using two products then need to upgrade both - Cost of upgrading
2	Compatibility	- Need third party or another product to interface - Knowledge of what works with what - Equipment compatibility - Software - Hardware (user interface) interoperability
4	Knowledge of what equipment can do	- Analytical experience - Objective analysis - Impartial recommendation
6	Support	- Equipment not used to capacity - Deemed all too hard when not used

8.13 Questionnaire 2. Interview 3

Interview 3
Position: Grower/Expert

Date: 1/08/2012
Location: Bundaberg District

MOST IMPORTANT PROBLEMS

nr	*Problem*	*Risk factors*
19	Drainage	- topography - soil type clay subsoil - unseasonal rain - harvest damage
25	Variety suitability	- Longevity - Production - Disease/pest resistance
18	Irrigation water system	- drought - irrigation inefficiencies - cost/ML to purchase scheme water - increased pumping costs
2/3/12	Soil types/soil depth/structure	- reduced yields - poor nutritional holding capacity - salinity - inability to laser level for drainage
42	Proper machinery	- Timely operations - Efficient operation
	Market fluctuations for sugar	- Volatile world sugar prices
44/3	technologies	- High degree of complicated electronics - Distance from suitable on farm service - Technologically very advanced eg. The use if a computer to analysis mechanical problems. - Inbuilt safe guards and shut off equipment
	Stable long term workforce Labour	- Holding key staff - Training and then loosing staff - Motivated staff - Higher pay in the mines
23/24	Harvest	- Stool damage – harvest to fast, blunt base cutters, driving haul outs on stool - Equipment maintenance - Moisture levels to allow optimum ratooning
38	rainfall	- Severity/amount (too much) - Nutrient loss - erosion

MOST IMPORTANT TECHNOLOGICAL PROBLEMS

nr	*Problem*	*Risk factors*
21	topography	- drainage - erosion - run off
45	Managers tools	- Not used at all - Not used correctly - training
6	support	- Not available for on farm support ieusually based too far away from the farm - Lack of ability to communicate support

COMMENTS

When completed this will be a very valuable management tool and I look forward to its development

I choose 12 as my factor to move problems through to the second section but I have also included:

- Labour
- Product marketing

As potential problems in the sugar industry to effect productivity.

General description of the majority of farms managed by BPF:

- Poor drainage due to topography and shallow top soils over an impermeable clay sub soil
- Mainly flood irrigation with some overhead (90ha pivot)
- Cane production with a rotation of legumes (peanuts or soybeans)
- All varieties a maximum of 4 years old
- Total production 75,000t
- Managed under the guidelines of a QMS.

8.14 Questionnaire 2. Interview 4

Interview 4
Occupation: Expert/Researcher

Date: 1/08/2012
Location: Bundaberg District

MOST IMPORTANT PROBLEMS

nr	*Problem*	*Risk factors*
3	Soil bulk density (Compaction)	- Machinery driving over stool - Reduced productivity - Increased water runoff, decreased infiltration
5	Soil organic matter	- Poor soil health or fertility - Removing trash - Burning crop trash - Not including break crop
13	Pests	- Cane grubs controlled by few chemicals - Pest incursion - Rising cost of chemicals -> may limit use
14	Diseases	- Disease outbreak - Disease incursion - Cost associated in changing to "new" resistant varieties - Rising cost of chemicals -> may limit use
15	Weeds	- Loss of crop production - Wasted water & fertilizer - Weed seed bank
20	Nutrient losses	- Depleting resource - Losses → Environmental issues - Cost associated with lost fertilizer
29	Planting costs	- Increased fuel and fertilizer costs - Takes crop from mill - High planting rates
38	Rainfall	- Too much - Too little - Not being able to adapt to forecasts
45	Harvest losses	- Significant loss of crop already grown and paid for - Increased harvesting costs
51	Harvest costs	- Increased fuel costs - No "bonus" for a good job - Supply of drivers

MOST IMPORTANT TECHNOLOGICAL PROBLEMS

nr	*Problem*	*Risk factors*
2	Compatibility	- Happening more often as new technologies are introduced
4	Knowledge of what you can do with the answer / output	- Users incorrectly using technology outputs - Lack of awareness of capability - Lack of technical support
6	Support	- Support from commercial suppliers can vary greatly - More salesman than technicians come with products
8	Yield monitors	- Reliable monitors need to be available commercially - Lack of capability to process data → yield maps

8.15 Questionnaire 2. Interview 5

Interview 5 **Date:** 1/08/2012

Occupation: Expert/Researcher **Location:** Wet tropics

MOST IMPORTANT PROBLEMS

nr	*Problem*	*Risk factors*
4	Soil Cation Exchange Capacity	- Nutrient needs - Ability to hold onto nutrients - Ameliorants/Products
15	Weeds	- Timing of control measures - Knowledge of integrated control - Use of technology
19	Drainage/Waterlogging	- High rainfall - Topography - Lack of infield drainage
20	Runoff/Leaching/Losses	- Loss of applied nutrients/amendments/products - Water quality issues
25	Variety selection	- Appropriate varieties for local circumstance - Variety productivity
27	Ratoon number	- Loss of productivity/yield as ratoon number increases - Gaps in cane, soil factors
28	Planting (establishment)	- Poor strike in same circumstances - Planting techniques (minimum till) - Cost
44	Manager's knowledge	- Inability to access information - Use of outdated practices - Use of untested practices
45	Harvesting losses	- Differences between actual yield and harvested yield - Inefficiency - Sugar loss in field
47	Natural calamities	- Cyclones, wind, excessive rain - Re-establishment costs - Loss of yield and sugar

MOST IMPORTANT TECHNOLOGICAL PROBLEMS

nr	*Problem*	*Risk factors*
3	Knowledge of what equipment can do	- What is available - What is appropriate
4	Knowledge of what you do with answer / output	- Large amount of data - What does it mean - How can it be used to make cane production
8	Yield monitors	- More sustainable - What is appropriate - Accuracy of data - Interpretation
9	Yield/Cost/Profit or other benefits	- What will it deliver - Economics - Other farm costs/requirements

8.16 Questionnaire 2. Interview 6

Interview 6
Occupation: Manager of HCPSC

Date: 17/08/2012
Location: Herbert-Ingham

MOST IMPORTANT PROBLEMS

nr	*Problem*	*Risk factors*
46	Harvesting costs	- Costs general - Multiple row harvesting required - Fuel costs - Machine through put
	Fertiliser costs	- General costs increasing - Optimum rates required based upon price
25	Variety selection	- Availability of new varieties - Longer ratoons - Soil suitability - Lack of choice
	Drainage/Waterlogging	- Cost - Cross regional planning
	Pests	- Cost - Limited options for control - Cross farm impacts (i.e. pigs, grubs)
	Disease	- Plant breeding - Risk mitigation - Quarantine - Variety rotation
	Compaction	- Heavy machinery - Unseen losses - Lack of belief of issue - Not matching row spacing + machinery
	Weeds	- Lack of alternatives - Cost of chemical control - Timing
	Harvesting losses	- The hidden losses - Industry not prepared to address issue - Environmental issues (juice on trash) - Lack of value chain acknowledgment
	Managers knowledge	- Generational change - Average age - Off farm job - Lack of time available

MOST IMPORTANT TECHNOLOGICAL PROBLEMS

nr	*Problem*	*Risk factors*
2	Compatibility	- Need compatibility between all systems (no silo please)
1	Obsolescence	- Very expensive
7	Cost	- Small farm size to just expenses for PA and other issues
8	Yield monitors	- Accurate cane consignment required

COMMENTS

The biggest challenge for the cane industry is to reduce or contain costs.

- Nutrient application is expensive and needs to be considered when developing a management strategy.
- Harvesting costs need serious attention. The only ways to reduce/contain cost are to increase throughput/hour by either wider swath harvesting or new harvesting methods.
- Politics + lack of integration across the value chain costs the industry lots of dollars.

8.17 Questionnaire 2. Interview 7

Interview 7
Occupation: GIS and Precision Ag Co-ordinator

Date: 17/08/2012
Location: Herbert-Ingham

MOST IMPORTANT PROBLEMS

nr	*Problem*	*Risk factors*
	Soil Ph	- Cost - Extension - Age of farmers - Lack of quick Ph analysis
	Compaction	- Heavier machinery - Lack of analysis - No enterprise view of supply chain
	Pests	- Lack of affordable control - Education of growers - Environmental factors
	Disease	- Quarantine - Breeding programs - Grower education
	Drainage	- Costs - Lack of Cause-Effect analysis - Politics and no district plan
	Variety selection	- Driven by planting contractors - Difficult to analyse variety performance - Lack of choice
	Crop rotation	- Not driven by economics - Harvesting and machine damage impacts crop rotation
	Row spacing	- Not enough analysis - Weeds vs. compaction vs. cost
	Proper machinery	- Not purchased on a fit for purpose base - Not geared to row space
	Manager's knowledge	- Generational change - Age - Smarter farmers getting higher paid jobs off farm

MOST IMPORTANT TECHNOLOGICAL PROBLEMS

nr	*Problem*	*Risk factors*
1	Compatibility	- No fit for purpose analysis
2	Obsolescence	- Expense of new equipment
4	Knowledge	- Ability to report and analyse outstripping farmers ability and adaptability - Sugar lagging other primary industries
8	Yield monitors	- Growers not understanding opportunities of yield monitors - Cost + knowledge + create yield monitors - Accurate block consignment

2.1 COMMENTS

Although it is difficult to achieve, agriculture needs to be seen as part of the entire supply chain. A holistic view needs to be adopted in Australian cane growing, similar to large plantations in Brazil where BMP can be rolled out rapidly.
Politics, small silos of information and farmers regarding themselves as individual as opposed to part of a bigger picture are all problem areas for sugar.

8.18 Questionnaire 2. Interview 8

Interview 8 **Date:** 23/08/2012
Occupation: Farm Manager **Location:** Ingham

MOST IMPORTANT PROBLEMS

nr	*Problem*	*Risk factors*
13	Pests	- Breeding cycle, environmental conditions. - Habitat in adjacent lands - Population of natural predators - Cost of available control methods
15	Weeds	- Environmental conditions - Weeds building resistance to chemicals applied - Reduced number and type of registered chemicals - Longevity of seed viability
25	Variety selection	- Lack of varieties to suit soil type - New varieties untried, unproven - Farm dominated by 1 or 2 varieties - Exposure to a disease incursion eg rusts.
26	Crop rotation	- Age or ratoons - Replanting, fallow plant. - Break cropping to reduce soil pathogens. - A full 12 month fallow.
36	Rainfall	- When will it rain - When will it stop - How much is coming once it starts - Every day of rain is a day closer to the sun shine.
43	Manager's tools	- Machinery in service. - Forward planning – harvest schedules - Matching varieties with specific blocks - Monitoring crop performance - yields
44	Manager's knowledge	- Not knowing reasons why? - Doing what the neighbours do. - Spending too much time on low value jobs
45	Harvesting losses (ground job, chopper losses, forward speed, extractor losses, …)	- Operator knowledge – experience. - Harvester maintenance- serviced - Harvester design capabilities - Crop conditon
46	Harvesting costs	- Row width. - Distance from siding - Soil conditions in the field. - Operator style, habits - Crop condition – yield - Row direction and length. - Farm topography - Changing paddocks more frequently then should be necessary chasing CCS

		- Crop presentation to the harvester – mound profile. - Fewer contractors – less competition for cane.
47	Performance of chemical application	- The most expensive chemical is the one that doesn't do the required job. - Weather conditions - Mill mud application - faulty product- recalled by company - weed pressures

MOST IMPORTANT TECHNOLOGICAL PROBLEMS

nr	*Problem*	*Risk factors*
2	Compatibility	- Farmers GPS - contractors GPS units need to communicate - Transfer of data without distortion - Add on equipment suitable for all makes/ models
3	Knowledge of what equipment can do	- Sticking to what we know. - Limited after sales support. - Unwillingness to get educated on new ideas.
4	Knowledge of what you do with the answer/output	- Ignorance - Is the info useful or applicable - Is the output accurate - reliable - Can I get the same answer easier – KISS technology
6	Support	- After sales support important - Upgrading software over time - Informing – education of customers - Growers need to be informed of technology improvements.

COMMENTS

Other technological problems are the cost of the GPS equipment. In our own experience, the purchase cost was one hurdle overcome with the help of grants through SRDC or government agencies, to the tune of a 50% subsidy. However the cost of maintaining the equipment has been all our own. Once electronics get 5 years old, they generally have issues and our GPS equipment operating in the on farm environment of humidity and dust is no exception. We have spent more than $9000 replacing or repairing GPS components on our first GPS unit after the first 5 years.
If a grower has more than one unit, as we do, then the expectation is this repair cost will rise accordingly.
The problem is getting a cost benefit by investing in guidance technology. When it is all said and done, we have spent heaps of money to achieve straight drills, and very little else. That being said, it is acknowledged that we have reduced our harvester losses, removed short rows, reduced soil compaction, and improved our working efficiency however all this has come at a significant cost and if we were to just look at our profit generated by investing in this technology you might wonder why we did it……
Farming this way is easier, no doubt, however it is certainly more expensive.

8.19 Questionnaire 2. Interview 9

Interview 9
Occupation: Research assistant

Date: 24/08/2012
Location: Ingham

2.2 MOST IMPORTANT PROBLEMS

nr	*Problem*	*Risk factors*
5	Soil organic matter	- Excessive tillage
13	Pests	- Regulation by governments of pesticides
14	Diseases	- Incursion of new diseases
15	Weeds	- Regulation of herbicides
19	Drainage	- Earth moving costs
23	Harvest date	- Late finish to crush
45	Harvesting losses	- Driver training (guidance)
46	Harvesting costs	- Availability of labour - Oil price - Exchange rate
3	Compaction	- Driver training (guidance)
7	Runoff	- Regulation by governments

2.3 MOST IMPORTANT TECHNOLOGICAL PROBLEMS

nr	*Problem*	*Risk factors*
2	Compatibility	- Rapid change in technology
4	Knowledge	- Age of farming community is increasing
7	Cost	- Oil price - Uncertain return on investment
9	Profit	- Exchange rate - Government regulations

8.20 Questionnaire 3. Interview 1

Interview 1 **Date:** 31/08/2012
Occupation: Farm Manager **Location:** Ingham

RISK FACTORS FOR PROBLEMS

Problem	*Risk factor*	*Severity (1-5)*	*Frequency (1-5)*
Harvest	Operator knowledge/training, experience	2	3
	Operator information feedback systems	3	3
	Soil condition	4	4
	Crop condition	4	3
	Crop presentation to harvester	3	3
	Harvester design	4	5
	Differences between actual yield and harvested yield	4	5
	Inefficiency	4	4
	Sugar loss in field	5	5
	Stool disease susceptibility	4	3
	CCS decrease due to extraneous matter on the stool sent to mill	3	3
	Stool damage – harvest too fast, blunt base cutters, driving haul outs on stool	4	5
	Equipment maintenance	4	4
	Moisture levels to allow optimum ratooning	3	3
	Harvesting date	3	3
	Increased costs, fuel	3	3
	Multiple row harvesting required	3	3
	Machine through put (work rate)	4	4
	Hidden losses	5	5
	Lack of value chain acknowledgment	4	4
	Environmental issues (juice on trash)	3	5
	Industry not prepared to address issue	3	5
	Variety	4	4
	Social issues (strikes)	4	2
	Likelihood rain	4	3
	Fewer contractors-less competition for cane	4	4
	Distance from siding	3	3
	Row width	3	4
	No bonus for a good job	3	5
	Supply of workers (drivers,labour)	3	3

Variety selection	Grower's knowledge	4	3
	Availability of decision tools	4	3
	Continued supply of varieties	5	4
	Cost	4	5
	Propagation time	4	5
	Risk management	3	4
	Appropriate varieties for local circumstance	5	3
	Variety productivity	5	2
	Disease/pest resistance	5	2
	New varieties unproven on farm	4	3
	Driven by planting contractors	3	3
	Difficult to analyse variety performance	3	3
	Lack of choice	3	3
	Availability of new varieties	5	3
	Longer ratoons	4	3
	Farm dominated by 1 or 2 varieties	5	4
	Longevity	4	3
Rainfall	When it will start/stop	4	3
	Severity/amount (too much/too little)	4	4
	Not being able to adapt to forecasts	3	3
	Nutrient loss	3	3
	Erosion	3	3
Soil bulk density(compaction)	Heavier machinery	4	5
	Lack of analysis	4	3
	Driver training (guidance)	4	4
	Axle load	4	4
	Controlled traffic	4	4
	Soil moisture	3	3
	Sol type	3	3
	Machinery driving on stool	4	4
	Reduced productivity	4	4
	Increases water runoff, decreased water infiltration	4	4
	Lack of belief of issue	4	4
	Not matching row spacing and machinery	4	3
	Unseen losses	4	3
Pests	Cane grubs controlled by a few chemicals	4	4
	Breeding cycle, environmental conditions	4	4
	Pest incursion	4	3
	Yield suppression	4	2
	Reduced nutrient efficiency	4	2

	Cost of available control methods	3	4
	Limited options for control	3	4
	Cross farm impact (i.e. pigs, grubs)	4	4
	Ratooning reduction	4	3
	Education of growers	3	3
	Environmental factors	3	3
	Low biodiversity/Natural enemies	3	4
	Pest vectors/pressure	4	3
	Existence of control mechanisms	3	4
	Regulation by Governments of pesticides	4	4
	Potential insect resistance	4	3
Manager's knowledge	Generational change	3	3
	Average age	3	5
	Off farm job	3	4
	Lack of time available	4	4
	Inability to access information	3	3
	Use of out-dated practices	3	3
	Use of untested practices	4	3
	Can be one dimensional	3	3
	Not knowing reasons why?	4	3
	Doing what the neighbours do	3	5
	Spend too much time on low value jobs	3	4

RISK FACTORS FOR TECHNOLOGICAL PROBLEMS

Problem	*Risk factor*	*Severity (1-5)*	*Frequency (1-5)*
Compatibility	Transfer of data without distortion	4	4
	Add on equipment for all models/makes	4	4
	GPS units need to communicate	4	2
	Systems need to communicate	4	2
	No fit for purpose analysis	4	2
	Rapid change in technology	4	4
	Need 3rd party or another product to interface	3	3
	Knowledge of what works with what	4	3
	Software and hardware interoperability	4	2
Knowledge of what to do with answer/output	Ignorance	4	4
	Is the info useful or applicable	3	4
	Accuracy/reliability of output	4	3
	Easier ways to get same answer (KISS technology)	3	4
	Ability to report and analyse	4	3
	Sugar lagging other primary industries	3	3

	Ageing of farming community	3	3
	Analytical experience	3	3
	Objective/impartial analysis	4	3
	Impartial recommendation	3	4
	Incorrect use of technology outputs	4	3
	Lack of awareness of capability	3	4
	Lack of technical support	3	4
	Large amounts of data	3	4
	How can it be used to make cane production	4	3
Yield/Cost/Profit or other benefit (legal, environmental, …)	Government regulations	5	4
	Perception by the grower	5	5
	What will it deliver	4	4
	Economics	4	4
	Other farm costs/requirements	4	3
Cost	Uncertain return on investment	4	4
	Small farm size to just expenses for PA and other issues	4	4

COMMENTS

I interpreted some of the questions to express a previous question in another way. Perhaps a little confused right now, not interested in any more surveys at this stage. Thanks.

8.21 Questionnaire 3. Interview 2

Interview 2
Occupation: Sugar cane farmer

Date: 5/09/2012
Location: Ayr

RISK FACTORS FOR PROBLEMS

Problem	*Risk factor*	*Severity (1-5)*	*Frequency (1-5)*
Harvest	Operator knowledge/training, experience	5	4
	Operator information feedback systems	4	3
	Soil condition	4	3
	Crop condition	4	3
	Crop presentation to harvester	3	3
	Harvester design	3	3
	Differences between actual yield and harvested yield	5	4
	Inefficiency	4	3
	Sugar loss in field	5	3
	Stool disease susceptibility	3	2
	CCS decrease due to extraneous matter on the stool sent to mill	4	3
	Stool damage – harvest too fast, blunt base cutters, driving haul outs on stool	4	4
	Equipment maintenance	3	2
	Moisture levels to allow optimum ratooning	3	3
	Harvesting date	4	3
	Increased costs, fuel	4	2
	Multiple row harvesting required	2	1
	Machine through put (work rate)	3	2
	Hidden losses	2	2
	Lack of value chain acknowledgment	3	2
	Environmental issues (juice on trash)	2	2
	Industry not prepared to address issue	2	2
	Variety	4	3
	Social issues (strikes)	4	2
	Likelihood rain	5	2
	Fewer contractors-less competition for cane	4	2
	Distance from siding	2	2
	Row width	3	2
	No bonus for a good job	2	1
	Supply of workers (drivers,labour)	2	2
Variety selection	Grower's knowledge	3	2

	Availability of decision tools	3	3
	Continued supply of varieties	4	2
	Cost	5	2
	Propagation time	3	2
	Risk management	3	3
	Appropriate varieties for local circumstance	4	3
	Variety productivity	4	3
	Disease/pest resistance	4	3
	New varieties unproven on farm	3	2
	Driven by planting contractors	2	1
	Difficult to analyse variety performance	3	2
	Lack of choice	4	4
	Availability of new varieties	4	4
	Longer ratoons	4	3
	Farm dominated by 1 or 2 varieties	3	3
	Longevity	4	3
Rainfall	When it will start/stop	4	3
	Severity/amount (too much/too little)	3	3
	Not being able to adapt to forecasts	3	3
	Nutrient loss	3	3
	Erosion	2	2
Soil bulk density (compaction)	Heavier machinery	4	3
	Lack of analysis	3	2
	Driver training (guidance)	2	2
	Axle load	2	2
	Controlled traffic	4	3
	Soil moisture	3	3
	Sol type	3	2
	Machinery driving on stool	4	2
	Reduced productivity	4	2
	Increases water runoff, decreased water infiltration	3	2
	Lack of belief of issue	2	2
	Not matching row spacing and machinery	2	2
	Unseen losses	3	2
Pests	Cane grubs controlled by a few chemicals	4	2
	Breeding cycle, environmental conditions	3	2
	Pest incursion	3	2
	Yield suppression	4	2
	Reduced nutrient efficiency	4	3
	Cost of available control methods	4	2
	Limited options for control	3	2
	Cross farm impact (i.e. pigs, grubs)	2	2
	Ratooning reduction	4	2

	Education of growers	3	2
	Environmental factors	2	2
	Low biodiversity/Natural enemies	3	2
	Pest vectors/pressure	4	2
	Existence of control mechanisms	4	2
	Regulation by Governments of pesticides	4	2
	Potential insect resistance	3	1
Manager's knowledge	Generational change	4	1
	Average age	4	2
	Off farm job	1	1
	Lack of time available	4	2
	Inability to access information	4	3
	Use of out-dated practices	2	1
	Use of untested practices	3	2
	Can be one dimensional	3	2
	Not knowing reasons why?	4	2
	Doing what the neighbours do	2	2
	Spend too much time on low value jobs	1	1

RISK FACTORS FOR TECHNOLOGICAL PROBLEMS

Problem	*Risk factor*	*Severity (1-5)*	*Frequency (1-5)*
Compatibility	Transfer of data without distortion	5	2
	Add on equipment for all models/makes	4	2
	GPS units need to communicate	5	2
	Systems need to communicate	4	2
	No fit for purpose analysis	3	2
	Rapid change in technology	3	3
	Need 3rd party or another product to interface	3	3
	Knowledge of what works with what	3	2
	Software and hardware interoperability	4	3
Knowledge of what to do with answer/output	Ignorance	4	2
	Is the info useful or applicable	4	3
	Accuracy/reliability of output	4	3
	Easier ways to get same answer (KISS technology)	3	2
	Ability to report and analyse	3	2
	Sugar lagging other primary industries	4	3
	Ageing of farming community	4	3
	Analytical experience	3	3
	Objective/impartial analysis	4	3
	Impartial recommendation	4	3
	Incorrect use of technology outputs	4	3

	Lack of awareness of capability	5	3
	Lack of technical support	5	3
	Large amounts of data	4	3
	How can it be used to make cane production	4	4
Yield/Cost/Profit or other benefit (legal, environmental, …)	Government regulations	3	5
	Perception by the grower	4	3
	What will it deliver	4	3
	Economics	4	3
	Other farm costs/requirements	4	2
Cost	Uncertain return on investment	4	4
	Small farm size to just expenses for PA and other issues	5	2

8.22 Questionnaire 3. Interview 3

Interview 3 **Date:** 8/09/2012
Occupation: Research assistant **Location:** Ingham

RISK FACTORS FOR PROBLEMS

Problem	*Risk factor*	*Severity (1-5)*	*Frequency (1-5)*
Harvest	Operator knowledge/training, experience	4	4
	Operator information feedback systems	3	3
	Soil condition	3	3
	Crop condition	3	3
	Crop presentation to harvester	3	3
	Harvester design	5	5
	Differences between actual yield and harvested yield	3	4
	Inefficiency	5	5
	Sugar loss in field	5	5
	Stool disease susceptibility	3	3
	CCS decrease due to extraneous matter on the stool sent to mill	3	3
	Stool damage – harvest too fast, blunt base cutters, driving haul outs on stool	4	4
	Equipment maintenance	3	3
	Moisture levels to allow optimum ratooning	3	3
	Harvesting date	3	3
	Increased costs, fuel	3	3
	Multiple row harvesting required	2	2
	Machine through put (work rate)	3	3
	Hidden losses	4	4
	Lack of value chain acknowledgment	5	5
	Environmental issues (juice on trash)	3	2
	Industry not prepared to address issue	3	3
	Variety	2	1
	Social issues (strikes)	3	3
	Likelihood rain	3	3
	Fewer contractors-less competition for cane	3	3
	Distance from siding	2	2
	Row width	4	4
	No bonus for a good job	4	4
	Supply of workers (drivers,labour)	4	4

Variety selection	Grower's knowledge	3	3
	Availability of decision tools	3	3
	Continued supply of varieties	2	1
	Cost	3	3
	Propagation time	1	1
	Risk management	2	3
	Appropriate varieties for local circumstance	1	1
	Variety productivity	1	1
	Disease/pest resistance	2	2
	New varieties unproven on farm	1	1
	Driven by planting contractors	3	3
	Difficult to analyse variety performance	1	1
	Lack of choice	1	1
	Availability of new varieties	1	1
	Longer ratoons	2	1
	Farm dominated by 1 or 2 varieties	2	2
	Longevity	2	2
Rainfall	When it will start/stop	2	2
	Severity/amount (too much/too little)	2	2
	Not being able to adapt to forecasts	2	2
	Nutrient loss	3	3
	Erosion	1	1
Soil bulk density(compaction)	Heavier machinery	4	4
	Lack of analysis	4	4
	Driver training (guidance)	5	5
	Axle load	4	4
	Controlled traffic	5	5
	Soil moisture	4	4
	Sol type		
	Machinery driving on stool	4	4
	Reduced productivity	5	5
	Increases water runoff, decreased water infiltration	5	5
	Lack of belief of issue	4	4
	Not matching row spacing and machinery	4	5
	Unseen losses	4	4
Pests	Cane grubs controlled by a few chemicals	1	1
	Breeding cycle, environmental conditions	1	1
	Pest incursion	1	1
	Yield suppression	2	2
	Reduced nutrient efficiency	1	1

	Cost of available control methods	2	2
	Limited options for control	1	1
	Cross farm impact (i.e. pigs, grubs)	1	1
	Ratooning reduction	2	2
	Education of growers	2	3
	Environmental factors	1	1
	Low biodiversity/Natural enemies	2	2
	Pest vectors/pressure	2	2
	Existence of control mechanisms	2	2
	Regulation by Governments of pesticides	3	4
	Potential insect resistance	3	3
Manager's knowledge	Generational change	3	3
	Average age	3	2
	Off farm job	3	3
	Lack of time available	3	3
	Inability to access information	2	2
	Use of out-dated practices	4	4
	Use of untested practices	4	4
	Can be one dimensional	3	3
	Not knowing reasons why?	3	3
	Doing what the neighbours do	3	3
	Spend too much time on low value jobs	3	3

RISK FACTORS FOR TECHNOLOGICAL PROBLEMS

Problem	*Risk factor*	*Severity (1-5)*	*Frequency (1-5)*
Compatibility	Transfer of data without distortion	3	3
	Add on equipment for all models/makes	3	3
	GPS units need to communicate	3	3
	Systems need to communicate	3	3
	No fit for purpose analysis	3	3
	Rapid change in technology	2	3
	Need 3rd party or another product to interface	3	2
	Knowledge of what works with what	3	3
	Software and hardware interoperability	3	3
Knowledge of what to do with answer/output	Ignorance	2	3
	Is the info useful or applicable	3	3
	Accuracy/reliability of output	3	3
	Easier ways to get same answer (KISS technology)	3	3
	Ability to report and analyse	3	3
	Sugar lagging other primary industries	2	2

	Ageing of farming community	2	2
	Analytical experience	2	3
	Objective/impartial analysis	3	3
	Impartial recommendation	3	4
	Incorrect use of technology outputs	2	3
	Lack of awareness of capability	3	3
	Lack of technical support	3	3
	Large amounts of data	3	3
	How can it be used to make cane production	3	3
Yield/Cost/Profit or other benefit (legal, environmental, …)	Government regulations	5	5
	Perception by the grower	4	4
	What will it deliver	3	3
	Economics	3	3
	Other farm costs/requirements	3	3
Cost	Uncertain return on investment	3	3
	Small farm size to just expenses for PA and other issues	3	4

8.23 Questionnaire 3. Interview 4

Interview 4 **Date:** 4/09/2012
Occupation: Principal Technician **Location:** Bundaberg

RISK FACTORS FOR PROBLEMS

Problem	*Risk factor*	*Severity (1-5)*	*Frequency (1-5)*
Harvest	Operator knowledge/training, experience	3	3
	Operator information feedback systems	1	1
	Soil condition	2	2
	Crop condition	3	1
	Crop presentation to harvester	3	3
	Harvester design	1	1
	Differences between actual yield and harvested yield	1	1
	Inefficiency	3	3
	Sugar loss in field	4	4
	Stool disease susceptibility	1	2
	CCS decrease due to extraneous matter on the stool sent to mill	2	1
	Stool damage – harvest too fast, blunt base cutters, driving haul outs on stool	4	3
	Equipment maintenance	1	1
	Moisture levels to allow optimum ratooning	3	2
	Harvesting date	4	2
	Increased costs, fuel	3	3
	Multiple row harvesting required	1	1
	Machine through put (work rate)	3	3
	Hidden losses	4	3
	Lack of value chain acknowledgment	3	4
	Environmental issues (juice on trash)	1	1
	Industry not prepared to address issue	2	2
	Variety	1	1
	Social issues (strikes)	1	1
	Likelihood rain	2	3
	Fewer contractors-less competition for cane	1	1
	Distance from siding	2	2
	Row width	3	3
	No bonus for a good job	4	4
	Supply of workers (drivers,labour)	3	3

Variety selection	Grower's knowledge	3	2
	Availability of decision tools	2	2
	Continued supply of varieties	1	1
	Cost	2	3
	Propagation time	2	2
	Risk management	2	2
	Appropriate varieties for local circumstance	1	1
	Variety productivity	3	3
	Disease/pest resistance	3	3
	New varieties unproven on farm	2	2
	Driven by planting contractors	3	2
	Difficult to analyse variety performance	1	1
	Lack of choice	1	2
	Availability of new varieties	1	1
	Longer ratoons	4	3
	Farm dominated by 1 or 2 varieties	2	2
	Longevity	4	3
Rainfall	When it will start/stop	3	3
	Severity/amount (too much/too little)	3	3
	Not being able to adapt to forecasts	3	4
	Nutrient loss	4	4
	Erosion	3	3
Soil bulk density(compaction)	Heavier machinery	4	4
	Lack of analysis	1	1
	Driver training (guidance)	2	2
	Axle load	2	2
	Controlled traffic	4	4
	Soil moisture	3	3
	Sol type	3	3
	Machinery driving on stool	5	4
	Reduced productivity	5	4
	Increases water runoff, decreased water infiltration	3	3
	Lack of belief of issue	4	4
	Not matching row spacing and machinery	4	4
	Unseen losses	1	1
Pests	Cane grubs controlled by a few chemicals	4	4
	Breeding cycle, environmental conditions	3	3
	Pest incursion	5	2
	Yield suppression	4	3
	Reduced nutrient efficiency	3	3

	Cost of available control methods	3	3
	Limited options for control	4	4
	Cross farm impact (i.e. pigs, grubs)	2	2
	Ratooning reduction	5	3
	Education of growers	3	3
	Environmental factors	3	3
	Low biodiversity/Natural enemies	3	3
	Pest vectors/pressure	2	2
	Existence of control mechanisms	4	4
	Regulation by Governments of pesticides	1	1
	Potential insect resistance	4	4
Manager's knowledge	Generational change	3	3
	Average age	4	3
	Off farm job	3	3
	Lack of time available	2	2
	Inability to access information	2	3
	Use of out-dated practices	3	3
	Use of untested practices	3	3
	Can be one dimensional	3	3
	Not knowing reasons why?	1	1
	Doing what the neighbours do	2	2
	Spend too much time on low value jobs	2	3

RISK FACTORS FOR TECHNOLOGICAL PROBLEMS

Problem	*Risk factor*	*Severity (1-5)*	*Frequency (1-5)*
Compatibility	Transfer of data without distortion	3	3
	Add on equipment for all models/makes	1	1
	GPS units need to communicate	1	1
	Systems need to communicate	1	1
	No fit for purpose analysis	1	1
	Rapid change in technology	3	3
	Need 3rd party or another product to interface	3	4
	Knowledge of what works with what	3	4
	Software and hardware interoperability	3	3
Knowledge of what to do with answer/output	Ignorance	2	2
	Is the info useful or applicable	3	3
	Accuracy/reliability of output	4	2
	Easier ways to get same answer (KISS technology)	2	2
	Ability to report and analyse	3	3
	Sugar lagging other primary industries	4	3

	Ageing of farming community	4	4
	Analytical experience	4	4
	Objective/impartial analysis	4	4
	Impartial recommendation	4	4
	Incorrect use of technology outputs	3	4
	Lack of awareness of capability	2	4
	Lack of technical support	2	4
	Large amounts of data	3	4
	How can it be used to make cane production	4	4
Yield/Cost/Profit or other benefit (legal, environmental, …)	Government regulations	2	2
	Perception by the grower	3	3
	What will it deliver	3	3
	Economics	4	4
	Other farm costs/requirements	1	1
Cost	Uncertain return on investment	4	4
	Small farm size to just expenses for PA and other issues	5	4

8.24 Questionnaire 3. Interview 5

Interview 5 **Date:** 3/09/2012
Occupation: **Location:**

RISK FACTORS FOR PROBLEMS

Problem	*Risk factor*	*Severity (1-5)*	*Frequency (1-5)*
Harvest	Operator knowledge/training, experience	5	5
	Operator information feedback systems	5	5
	Soil condition	4	4
	Crop condition	3	3
	Crop presentation to harvester	4	4
	Harvester design	5	5
	Differences between actual yield and harvested yield	5	5
	Inefficiency	3	5
	Sugar loss in field	4	4
	Stool disease susceptibility	3	3
	CCS decrease due to extraneous matter on the stool sent to mill	4	4
	Stool damage – harvest too fast, blunt base cutters, driving haul outs on stool	5	5
	Equipment maintenance	3	3
	Moisture levels to allow optimum ratooning	2	2
	Harvesting date	4	4
	Increased costs, fuel	3	3
	Multiple row harvesting required	2	5
	Machine through put (work rate)	3	3
	Hidden losses	3	3
	Lack of value chain acknowledgment	5	5
	Environmental issues (juice on trash)	2	2
	Industry not prepared to address issue	5	5
	Variety	5	5
	Social issues (strikes)	1	1
	Likelihood rain	2	5
	Fewer contractors-less competition for cane	4	4
	Distance from siding	1	2
	Row width	3	4
	No bonus for a good job	4	4
	Supply of workers (drivers,labour)	3	5

Variety selection	Grower's knowledge	4	4
	Availability of decision tools	2	2
	Continued supply of varieties	3	3
	Cost	3	3
	Propagation time	3	3
	Risk management	4	4
	Appropriate varieties for local circumstance	4	3
	Variety productivity	4	4
	Disease/pest resistance	3	3
	New varieties unproven on farm	3	3
	Driven by planting contractors	3	3
	Difficult to analyse variety performance	2	2
	Lack of choice	3	2
	Availability of new varieties	3	3
	Longer ratoons	5	5
	Farm dominated by 1 or 2 varieties	4	4
	Longevity	4	4
Rainfall	When it will start/stop	3	3
	Severity/amount (too much/too little)	4	3
	Not being able to adapt to forecasts	5	5
	Nutrient loss	3	3
	Erosion	2	2
Soil bulk density(compaction)	Heavier machinery	4	4
	Lack of analysis	4	4
	Driver training (guidance)	4	4
	Axle load	4	4
	Controlled traffic	4	4
	Soil moisture	4	3
	Sol type	4	3
	Machinery driving on stool	5	5
	Reduced productivity	4	5
	Increases water runoff, decreased water infiltration	3	3
	Lack of belief of issue	4	4
	Not matching row spacing and machinery	4	4
	Unseen losses	4	4
Pests	Cane grubs controlled by a few chemicals	5	4
	Breeding cycle, environmental conditions	4	4
	Pest incursion	3	3
	Yield suppression	3	3
	Reduced nutrient efficiency	3	3

	Cost of available control methods	4	4
	Limited options for control	4	4
	Cross farm impact (i.e. pigs, grubs)	5	3
	Ratooning reduction	4	3
	Education of growers	4	4
	Environmental factors	4	4
	Low biodiversity/Natural enemies	4	4
	Pest vectors/pressure	4	4
	Existence of control mechanisms	4	4
	Regulation by Governments of pesticides	5	5
	Potential insect resistance	3	3
Manager's knowledge	Generational change	4	4
	Average age	4	4
	Off farm job	4	3
	Lack of time available	4	3
	Inability to access information	1	1
	Use of out-dated practices	4	4
	Use of untested practices	3	3
	Can be one dimensional	5	5
	Not knowing reasons why?	4	4
	Doing what the neighbours do	4	4
	Spend too much time on low value jobs	3	3

RISK FACTORS FOR TECHNOLOGICAL PROBLEMS

Problem	*Risk factor*	*Severity (1-5)*	*Frequency (1-5)*
Compatibility	Transfer of data without distortion	4	4
	Add on equipment for all models/makes	2	2
	GPS units need to communicate	4	4
	Systems need to communicate	4	4
	No fit for purpose analysis	4	4
	Rapid change in technology	4	4
	Need 3rd party or another product to interface	4	4
	Knowledge of what works with what	4	4
	Software and hardware interoperability	5	5
Knowledge of what to do with answer/output	Ignorance	5	4
	Is the info useful or applicable	4	4
	Accuracy/reliability of output	4	4
	Easier ways to get same answer (KISS technology)	4	4
	Ability to report and analyse	5	5
	Sugar lagging other primary industries	2	2

	Ageing of farming community	4	4
	Analytical experience	4	4
	Objective/impartial analysis	4	4
	Impartial recommendation	4	4
	Incorrect use of technology outputs	4	4
	Lack of awareness of capability	4	4
	Lack of technical support	2	2
	Large amounts of data	4	4
	How can it be used to make cane production	4	4
Yield/Cost/Profit or other benefit (legal, environmental, …)	Government regulations	5	5
	Perception by the grower	5	5
	What will it deliver	5	5
	Economics	5	5
	Other farm costs/requirements	5	5
Cost	Uncertain return on investment	5	5
	Small farm size to just expenses for PA and other issues	5	5

3.1 COMMENTS

Where once all growers were roughly equal and their productivity rose and fell with such factors as rainfall we are now seeing a divergence from this historical trend.
Innovative growers are now using better decision making processes with available and gathered knowledge. Coupled with technological investments in PA - it is now evident from productivity records and yield monitoring programs that these innovative growers are growing measurably more cane than their neighbours regardless of the environment. The transition required to achieve this higher productivity is prohibitive for many of the older and less financial growers although the use of contractors could provide some opportunities for taking advantage of new farming techniques and systems.

8.25 Questionnaire 3. Results

									Severity				Frequency			
nr	*Problem*	*Risk factor*		*ONE*	*TWO*	*THREE*	*FOUR*	*FIVE*	*n*	*Median*	*Avg*	*IQR*	*n*	*Median*	*Avg*	*IQR*
1	Harvest	Operator knowledge/training, experience	Severity	4	5	3	5	2	5	4	3,8	2	5	4	3,8	1
			Frequency	4	5	3	4	3								
2		Operator information feedback systems	Severity	3	5	1	4	3	5	3	3,2	1	5	3	3	0
			Frequency	3	5	1	3	3								
3		Soil condition	Severity	3	4	2	4	4	5	4	3,4	1	5	3	3,2	1
			Frequency	3	4	2	3	4								
4		Crop condition	Severity	3	3	3	4	4	5	3	3,4	1	5	3	2,6	0
			Frequency	3	3	1	3	3								
5		Crop presentation to harvester	Severity	3	4	3	3	3	5	3	3,2	0	5	3	3,2	0
			Frequency	3	4	3	3	3								
6		Harvester design	Severity	5	5	1	3	4	5	4	3,6	2	5	5	3,8	2
			Frequency	5	5	1	3	5								
7		Differences between actual yield and harvested yield	Severity	3	5	1	5	4	5	4	3,6	2	5	4	3,8	1
			Frequency	4	5	1	4	5								
8		Inefficiency	Severity	5	3	3	4	4	5	4	3,8	1	5	4	4	2
			Frequency	5	5	3	3	4								
9		Sugar loss in field	Severity	5	4	4	5	5	5	5	4,6	1	5	4	4,2	
			Frequency	5	4	4	3	5								
10		Stool disease susceptibility	Severity	3	3	1	3	4	5	3	2,8	0	5	3	2,6	
			Frequency	3	3	2	2	3								
11		CCS decrease due to extraneous matter on the stool sent to mill	Severity	3	4	2	4	3	5	3	3,2	1	5	3	2,8	
			Frequency	3	4	1	3	3								
12		Stool damage – harvest too fast, blunt base cutters, driving haul outs on stool	Severity	4	5	4	4	4	5	4	4,2	0	5	4	4,2	
			Frequency	4	5	3	4	5								

									Severity				Frequency			
nr	Problem	Risk factor		ONE	TWO	THREE	FOUR	FIVE	n	Median	Avg	IQR	n	Median	Avg	IQR
13	Harvest	Equipment maintenance	Severity	3	3	1	3	4	5	3	2,8	0	5	3	2,6	1
			Frequency	3	3	1	2	4								
14		Moisture levels to allow optimum ratooning	Severity	3	2	3	3	3	5	3	2,8	0	5	3	2,6	1
			Frequency	3	2	2	3	3								
15		Harvesting date	Severity	3	4	4	4	3	5	4	3,6	1	5	3	3	0
			Frequency	3	4	2	3	3								
16		Increased costs, fuel	Severity	3	3	3	4	3	5	3	3,2	0	5	3	2,8	0
			Frequency	3	3	3	2	3								
17		Multiple row harvesting required	Severity	2	2	1	2	3	5	2	2	0	5	2	2,4	2
			Frequency	2	5	1	1	3								
18		Machine through put (work rate)	Severity	3	3	3	3	4	5	3	3,2	0	5	3	3	0
			Frequency	3	3	3	2	4								
19		Hidden losses	Severity	4	3	4	2	5	5	4	3,6	1	5	3	3,4	1
			Frequency	4	3	3	2	5								
20		Lack of value chain acknowledgment	Severity	5	5	3	3	4	5	4	4	2	5	4	4	1
			Frequency	5	5	4	2	4								
21		Environmental issues (juice on trash)	Severity	3	2	1	2	3	5	2	2,2	1	5	2	2,4	0
			Frequency	2	2	1	2	5								
22		Industry not prepared to address issue	Severity	3	5	2	2	3	5	3	3	1	5	3	3,4	3
			Frequency	3	5	2	2	5								
23		Variety	Severity	2	5	1	4	4	5	4	3,2	2	5	3	2,8	3
			Frequency	1	5	1	3	4								
24		Social issues (strikes)	Severity	3	1	1	4	4	5	3	2,6	3	5	2	1,8	1
			Frequency	3	1	1	2	2								

nr	Problem	Risk factor		ONE	TWO	THREE	FOUR	FIVE	Severity n	Severity Median	Severity Avg	Severity IQR	Frequency n	Frequency Median	Frequency Avg	Frequency IQR
25	Harvest	Likelihood rain	Severity	3	2	2	5	4	5	3	3,2	2	5	3	3,2	0
			Frequency	3	5	3	2	3								
26		Fewer contractors-less competition for cane	Severity	3	4	1	4	4	5	4	3,2	1	5	3	2,8	2
			Frequency	3	4	1	2	4								
27		Distance from siding	Severity	2	1	2	2	3	5	2	2	0	5	2	2,2	0
			Frequency	2	2	2	2	3								
28		Row width	Severity	4	3	3	3	3	5	3	3,2	0	5	4	3,4	1
			Frequency	4	4	3	2	4								
29		No bonus for a good job	Severity	4	4	4	2	3	5	4	3,4	1	5	4	3,6	0
			Frequency	4	4	4	1	5								
30		Supply of workers (drivers,labour)	Severity	4	3	3	2	3	5	3	3	0	5	3	3,4	1
			Frequency	4	5	3	2	3								
31	Variety selection	Grower's knowledge	Severity	3	4	3	3	4	5	3	3,4	1	5	3	2,8	1
			Frequency	3	4	2	2	3								
32		Availability of decision tools	Severity	3	2	2	3	4	5	3	2,8	1	5	3	2,6	1
			Frequency	3	2	2	3	3								
33		Continued supply of varieties	Severity	2	3	1	4	5	5	3	3	2	5	2	2,2	2
			Frequency	1	3	1	2	4								
34		Cost	Severity	3	3	2	5	4	5	3	3,4	1	5	3	3,2	0
			Frequency	3	3	3	2	5								
35		Propagation time	Severity	1	3	2	3	4	5	3	2,6	1	5	2	2,6	1
			Frequency	1	3	2	2	5								
36		Risk management	Severity	2	4	2	3	3	5	3	2,8	1	5	3	3,2	1
			Frequency	3	4	2	3	4								

nr	Problem	Risk factor		ONE	TWO	THREE	FOUR	FIVE	Severity n	Severity Median	Severity Avg	Severity IQR	Frequency n	Frequency Median	Frequency Avg	Frequency IQR
37	Variety selection	Appropriate varieties for local circumstance	Severity	1	4	1	4	5	5	4	3	3	5	3	2,2	2
			Frequency	1	3	1	3	3								
38	Variety selection	Variety productivity	Severity	1	4	3	4	5	5	4	3,4	1	5	3	2,6	1
			Frequency	1	4	3	3	2								
39	Variety selection	Disease/pest resistance	Severity	2	3	3	4	5	5	3	3,4	1	5	3	2,6	1
			Frequency	2	3	3	3	2								
40	Variety selection	New varieties unproven on farm	Severity	1	3	2	3	4	5	3	2,6	1	5	2	2,2	1
			Frequency	1	3	2	2	3								
41	Variety selection	Driven by planting contractors	Severity	3	3	3	2	3	5	3	2,8	0	5	3	2,4	1
			Frequency	3	3	2	1	3								
42	Variety selection	Difficult to analyse variety performance	Severity	1	2	1	3	3	5	2	2	2	5	2	1,8	1
			Frequency	1	2	1	2	3								
43	Variety selection	Lack of choice	Severity	1	3	1	4	3	5	3	2,4	2	5	2	2,4	1
			Frequency	1	2	2	4	3								
44	Variety selection	Availability of new varieties	Severity	1	3	1	4	5	5	3	2,8	3	5	3	2,4	2
			Frequency	1	3	1	4	3								
45	Variety selection	Longer ratoons	Severity	2	5	4	4	4	5	4	3,8	0	5	3	3	0
			Frequency	1	5	3	3	3								
46	Variety selection	Farm dominated by 1 or 2 varieties	Severity	2	4	2	3	5	5	3	3,2	2	5	3	3	2
			Frequency	2	4	2	3	4								
47	Variety selection	Longevity	Severity	2	4	4	4	4	5	4	3,6	0	5	3	3	0
			Frequency	2	4	3	3	3								
48	Rainfall	When it will start/stop	Severity	2	3	3	4	4	5	3	3,2	1	5	3	2,8	0
			Frequency	2	3	3	3	3								

nr	Problem	Risk factor		ONE	TWO	THREE	FOUR	FIVE	Severity n	Severity Median	Severity Avg	Severity IQR	Frequency n	Frequency Median	Frequency Avg	Frequency IQR
49	Rainfall	Severity/amount (too much/too little)	Severity	2	4	3	3	4	5	3	3,2	1	5	3	3	0
			Frequency	2	3	3	3	4								
50		Not being able to adapt to forecasts	Severity	2	5	3	3	3	5	3	3,2	0	5	3	3,4	1
			Frequency	2	5	4	3	3								
51		Nutrient loss	Severity	3	3	4	3	3	5	3	3,2	0	5	3	3,2	0
			Frequency	3	3	4	3	3								
52		Erosion	Severity	1	2	3	2	3	5	2	2,2	1	5	2	2,2	1
			Frequency	1	2	3	2	3								
53	Soil bulk density (compaction)	Heavier machinery	Severity	4	4	4	4	4	5	4	4	0	5	4	4	0
			Frequency	4	4	4	3	5								
54		Lack of analysis	Severity	4	4	1	3	4	5	4	3,2	1	5	3	2,8	2
			Frequency	4	4	1	2	3								
55		Driver training (guidance)	Severity	5	4	2	2	4	5	4	3,4	2	5	4	3,4	2
			Frequency	5	4	2	2	4								
56		Axle load	Severity	4	4	2	2	4	5	4	3,2	2	5	4	3,2	2
			Frequency	4	4	2	2	4								
57		Controlled traffic	Severity	5	4	4	4	4	5	4	4,2	0	5	4	4	0
			Frequency	5	4	4	3	4								
58		Soil moisture	Severity	4	4	3	3	3	5	3	3,4	1	5	3	3,2	0
			Frequency	4	3	3	3	3								
59		Soil type	Severity	-	4	3	3	3	4	3	3,25	0,25	4	3	2,75	0,25
			Frequency	-	3	3	2	3								
60		Machinery driving on stool	Severity	4	5	5	4	4	5	4	4,4	1	5	4	3,8	0
			Frequency	4	5	4	2	4								

nr	Problem	Risk factor		ONE	TWO	THREE	FOUR	FIVE	Severity n	Severity Median	Severity Avg	Severity IQR	Frequency n	Frequency Median	Frequency Avg	Frequency IQR
61	Soil bulk density (compaction)	Reduced productivity	Severity	5	4	5	4	4	5	4	4,4	1	5	4	4	1
			Frequency	5	5	4	2	4								
62		Increases water runoff, decreased water infiltration	Severity	5	3	3	3	4	5	3	3,6	1	5	3	3,4	1
			Frequency	5	3	3	2	4								
63		Lack of belief of issue	Severity	4	4	4	2	4	5	4	3,6	0	5	4	3,6	0
			Frequency	4	4	4	2	4								
64		Not matching row spacing and machinery	Severity	4	4	4	2	4	5	4	3,6	0	5	4	3,6	1
			Frequency	5	4	4	2	3								
65		Unseen losses	Severity	4	4	1	3	4	5	4	3,2	1	5	3	2,8	2
			Frequency	4	4	1	2	3								
66	Pests	Cane grubs controlled by a few chemicals	Severity	1	5	4	4	4	5	4	3,6	0	5	4	3	2
			Frequency	1	4	4	2	4								
67		Breeding cycle, environmental conditions	Severity	1	4	3	3	4	5	3	3	1	5	3	2,8	2
			Frequency	1	4	3	2	4								
68		Pest incursion	Severity	1	3	5	3	4	5	3	3,2	1	5	2	2,2	1
			Frequency	1	3	2	2	3								
69		Yield suppression	Severity	2	3	4	4	4	5	4	3,4	1	5	2	2,4	1
			Frequency	2	3	3	2	2								
70		Reduced nutrient efficiency	Severity	1	3	3	4	4	5	3	3	1	5	3	2,4	1
			Frequency	1	3	3	3	2								
71		Cost of available control methods	Severity	2	4	3	4	3	5	3	3,2	1	5	3	3	2
			Frequency	2	4	3	2	4								
72		Limited options for control	Severity	1	4	4	3	3	5	3	3	1	5	4	3	2
			Frequency	1	4	4	2	4								

nr	Problem	Risk factor		ONE	TWO	THREE	FOUR	FIVE	Severity n	Severity Median	Severity Avg	Severity IQR	Frequency n	Frequency Median	Frequency Avg	Frequency IQR
73	Pests	Cross farm impact (i.e. pigs, grubs)	Severity	1	5	2	2	4	5	2	2,8	2	5	2	2,4	1
			Frequency	1	3	2	2	4								
74		Ratooning reduction	Severity	2	4	5	4	4	5	4	3,8	0	5	3	2,6	1
			Frequency	2	3	3	2	3								
75		Education of growers	Severity	2	4	3	3	3	5	3	3	0	5	3	3	0
			Frequency	3	4	3	2	3								
76		Environmental factors	Severity	1	4	3	2	3	5	3	2,6	1	5	3	2,6	1
			Frequency	1	4	3	2	3								
77		Low biodiversity/Natural enemies	Severity	2	4	3	3	3	5	3	3	0	5	3	3	2
			Frequency	2	4	3	2	4								
78		Pest vectors/pressure	Severity	2	4	2	4	4	5	4	3,2	2	5	2	2,6	1
			Frequency	2	4	2	2	3								
79		Existence of control mechanisms	Severity	2	4	4	4	3	5	4	3,4	1	5	4	3,2	2
			Frequency	2	4	4	2	4								
80		Regulation by Governments of pesticides	Severity	3	5	1	4	4	5	4	3,4	1	5	4	3,2	2
			Frequency	4	5	1	2	4								
81		Potential insect resistance	Severity	3	3	4	3	4	5	3	3,4	1	5	3	2,8	0
			Frequency	3	3	4	1	3								
82	Manager's knowledge	Generational change	Severity	3	4	3	4	3	5	3	3,4	1	5	3	2,8	0
			Frequency	3	4	3	1	3								
83		Average age	Severity	3	4	4	4	3	5	4	3,6	1	5	3	3,2	2
			Frequency	2	4	3	2	5								
84		Off farm job	Severity	3	4	3	1	3	5	3	2,8	0	5	3	2,8	0
			Frequency	3	3	3	1	4								

nr	Problem	Risk factor		ONE	TWO	THREE	FOUR	FIVE	Severity n	Severity Median	Severity Avg	Severity IQR	Frequency n	Frequency Median	Frequency Avg	Frequency IQR
85	Manager's knowledge	Lack of time available	Severity	3	4	2	4	4	5	4	3,4	1	5	3	2,8	1
			Frequency	3	3	2	2	4								
86		Inability to access information	Severity	2	1	2	4	3	5	2	2,4	1	5	3	2,4	1
			Frequency	2	1	3	3	3								
87		Use of out-dated practices	Severity	4	4	3	2	3	5	3	3,2	1	5	3	3	1
			Frequency	4	4	3	1	3								
88		Use of untested practices	Severity	4	3	3	3	4	5	3	3,4	1	5	3	2,8	0
			Frequency	3	3	3	2	3								
89		Can be one dimensional	Severity	3	5	3	3	3	5	3	3,4	0	5	3	3,2	0
			Frequency	3	5	3	2	3								
90		Not knowing reasons why?	Severity	3	4	1	4	4	5	4	3,2	1	5	3	2,6	1
			Frequency	3	4	1	2	3								
91		Doing what the neighbours do	Severity	3	4	2	2	3	5	3	2,8	1	5	3	3,2	2
			Frequency	3	4	2	2	5								
92		Spend too much time on low value jobs	Severity	3	3	2	1	3	5	3	2,4	1	5	3	2,8	0
			Frequency	3	3	3	1	4								

nr	Problem	Risk factor		ONE	TWO	THREE	FOUR	FIVE	Severity				Frequency			
									n	*Median*	*Avg*	*IQR*	*n*	*Median*	*Avg*	*IQR*
1	Compatibility	Transfer of data without distortion	Severity	3	4	3	5	4	5	4	3,8	1	5	3	3,2	1
			Frequency	3	4	3	2	4								
2		Add on equipment for all models/makes	Severity	3	2	1	4	4	5	3	2,8	2	5	2	2,4	1
			Frequency	3	2	1	2	4								
3		GPS units need to communicate	Severity	3	4	1	5	4	5	4	3,4	1	5	2	2,4	1
			Frequency	3	4	1	2	2								
4		Systems need to communicate	Severity	3	4	1	4	4	5	4	3,2	1	5	2	2,4	1
			Frequency	3	4	1	2	2								
5		No fit for purpose analysis	Severity	3	4	1	3	4	5	3	3	1	5	2	2,4	1
			Frequency	3	4	1	2	2								
6		Rapid change in technology	Severity	2	4	3	3	4	5	3	3,2	1	5	3	3,4	1
			Frequency	3	4	3	3	4								
7		Need 3rd party or another product to interface	Severity	3	4	3	3	3	5	3	3,2	0	5	3	3,2	1
			Frequency	2	4	4	3	3								
8		Knowledge of what works with what	Severity	3	4	3	3	4	5	3	3,4	1	5	3	3,2	1
			Frequency	3	4	4	2	3								
9		Software and hardware interoperability	Severity	3	5	3	4	4	5	4	3,8	1	5	3	3,2	0
			Frequency	3	5	3	3	2								
10	Knowledge of what to do with answer/output	Ignorance	Severity	2	5	2	4	4	5	4	3,4	2	5	3	3	2
			Frequency	3	4	2	2	4								
11		Is the info useful or applicable	Severity	3	4	3	4	3	5	3	3,4	1	5	3	3,4	1
			Frequency	3	4	3	3	4								
12		Accuracy/reliability of output	Severity	3	4	4	4	4	5	4	3,8	0	5	3	3	0
			Frequency	3	4	2	3	3								

nr	Problem	Risk factor		ONE	TWO	THREE	FOUR	FIVE	Severity n	Severity Median	Severity Avg	Severity IQR	Frequency n	Frequency Median	Frequency Avg	Frequency IQR
13	Knowledge of what to do with answer/output	Easier ways to get same answer (KISS technology)	Severity	3	4	2	3	3	5	3	3	0	5	3	3	2
			Frequency	3	4	2	2	4								
14		Ability to report and analyse	Severity	3	5	3	3	4	5	3	3,6	1	5	3	3,2	0
			Frequency	3	5	3	2	3								
15		Sugar lagging other primary industries	Severity	2	2	4	4	3	5	3	3	2	5	3	2,6	1
			Frequency	2	2	3	3	3								
16		Ageing of farming community	Severity	2	4	4	4	3	5	4	3,4	1	5	3	3,2	1
			Frequency	2	4	4	3	3								
17		Analytical experience	Severity	2	4	4	3	3	5	3	3,2	1	5	3	3,4	1
			Frequency	3	4	4	3	3								
18		Objective/impartial analysis	Severity	3	4	4	4	4	5	4	3,8	0	5	3	3,4	1
			Frequency	3	4	4	3	3								
19		Impartial recommendation	Severity	3	4	4	4	3	5	4	3,6	1	5	4	3,8	0
			Frequency	4	4	4	3	4								
20		Incorrect use of technology outputs	Severity	2	4	3	4	4	5	4	3,4	1	5	3	3,4	1
			Frequency	3	4	4	3	3								
21		Lack of awareness of capability	Severity	3	4	2	5	3	5	3	3,4	1	5	4	3,6	1
			Frequency	3	4	4	3	4								
22		Lack of technical support	Severity	3	2	2	5	3	5	3	3	1	5	3	3,2	1
			Frequency	3	2	4	3	4								
23		Large amounts of data	Severity	3	4	3	4	3	5	3	3,4	1	5	4	3,6	1
			Frequency	3	4	4	3	4								
24		How can it be used to make cane production	Severity	3	4	4	4	4	5	4	3,8	0	5	4	3,6	1
			Frequency	3	4	4	4	3								

nr	Problem	Risk factor		ONE	TWO	THREE	FOUR	FIVE	Severity n	Severity Median	Severity Avg	Severity IQR	Frequency n	Frequency Median	Frequency Avg	Frequency IQR
25	Yield/Cost/Profit or other benefit (legal, environmental, ...)	Government regulations	Severity	5	5	2	3	5	5	5	4	2	5	5	4,2	1
			Frequency	5	5	2	5	4								
26		Perception by the grower	Severity	4	5	3	4	5	5	4	4,2	1	5	4	4	2
			Frequency	4	5	3	3	5								
27		What will it deliver	Severity	3	5	3	4	4	5	4	3,8	1	5	3	3,6	1
			Frequency	3	5	3	3	4								
28		Economics	Severity	3	5	4	4	4	5	4	4	0	5	4	3,8	1
			Frequency	3	5	4	3	4								
29		Other farm costs/requirements	Severity	3	5	1	4	4	5	4	3,4	1	5	3	2,8	1
			Frequency	3	5	1	2	3								
30	Cost	Uncertain return on investment	Severity	3	5	4	4	4	5	4	4	0	5	4	4	0
			Frequency	3	5	4	4	4								
31		Small farm size to just expenses for PA and other issues	Severity	3	5	5	5	4	5	5	4,4	1	5	4	3,8	0
			Frequency	4	5	4	2	4								

8.26 Questionnaire 4. Interview 1

Interview 1 **Date:** 10/10/2012
Occupation: Geospatial & PA systems officer **Location:** Herbert

LIST OF RISK FACTORS FOR THEIR CONTROL POINTS AND ALARM VALUES

nr	*Problem*	*Risk factor*	*Control Point(s)*	*Alarm value(s)*
1	Harvest	Sugar loss in field	- Harvester - Haul out	- No expert systems - No GPS on haul out
2		Harvester design	- Factory	- Upper management has no knowledge of issues
3		Stool damage – harvest too fast, blunt base cutters, driving haul outs on stool	- Operator - Farmer	- > 7 kph - Stools driven over
4		Lack of value chain acknowledgment	- Organizations	- Loss of practical people in Management
5		Inefficiency	- Education	- Growers don't know basics
6		Operator knowledge/training, experience	- TAFE accreditation	- Poor planning
7	Compaction	Reduced productivity	- Drill spacing	- 1.68 meters or less for cane
8		Controlled traffic	- Tractor - Harvester	- Slow - Adoption some areas
9		Machinery driving on stool	- Driver technology	- > 20% stool driven on
10		Heavier machinery	- Factory	- Production vs. productivity

COMMENTS

The industry needs to re-engage with the harvesting and growing side.
Failure to embed people with knowledge + experience of growing under PA and harvesting with management will see further declines in cane production as the important issues identified in this study go unaddressed.

8.27 Questionnaire 4. Interview 2

Interview 2
Occupation: Research assistant

Date: 11/10/2012
Location: Ingham

LIST OF RISK FACTORS FOR THEIR CONTROL POINTS AND ALARM VALUES

nr	*Problem*	*Risk factor*	*Control Point(s)*	*Alarm value(s)*
1	Harvest	Sugar loss in field	- Primary extractor fan speed - Number of chopper blades	- Over $700/ha - No more than 4
2		Harvester design	- Matching feed train roller speeds	?
3		Stool damage – harvest too fast, blunt base cutters, driving haul outs on stool	- Drivers - Farmers	?
4		Lack of value chain acknowledgment	- Industry	?
5		Inefficiency	?	?
6		Operator knowledge/training, experience	- Driver	?
7	Compaction	Reduced productivity	- Row space	- Less than 1,8 m.
8		Controlled traffic	- Drivers - Farmers	?
9		Machinery driving on stool	- Drivers - Farmers	?
10		Heavier machinery	- Factory	?

8.28 Questionnaire 4. Interview 3

Interview 3 **Date:** 10/10 2012
Occupation: HCPSC manager **Location:** Herbert

LIST OF RISK FACTORS FOR THEIR CONTROL POINTS AND ALARM VALUES

nr	*Problem*	*Risk factor*	*Control Point(s)*	*Alarm value(s)*
1		Sugar loss in field	Harvest	No feedback systems in place
2		Harvester design	Factory /manufacturer	
3		Stool damage – harvest too fast, blunt base cutters, driving haul outs on stool	Harvest	- Lost of harvesting - Poor ratoons
4	Harvest	Lack of value chain acknowledgment	Industry organisation	- Lack of people - With technological knowledge
5		Inefficiency	Whole of value chain	Poor planning
6		Operator knowledge/training, experience	Harvest	Poor understanding of the value chain
7		Reduced productivity	- Growers - Harvester	- Lack of CTF implementation - Confining traffic issue
8	Compaction	Controlled traffic	Growers	- Failure to comply or acknowledge problem
9		Machinery driving on stool	Harvest	< of stool driven on
10		Heavier machinery	Manufacturer	- Compaction issues - Productivity issues

COMMENTS

The harvesting sector are acting as free agents with little regard to addressing issues like compaction or cane quality. In many cases now the harvesting sector are impacting on the adoption of CTF systems.
The harvesting sector appears to have a lack of regard for the value chain issues like cane/sugar quality, compaction, cane consignment or impacts caused by harvesting; this sector of industry is solely driven by tons/hr through machines.