AN INVESTIGATION OF THE FEEDING CHARACTERISTICS OF THE
FORWARD-FEEDING ZONE OF CHOPPER HARVESTERS:
DEVELOPMENT OF A RESEARCH HARVESTER

By

R.J. DAVIS$^1$ and C.P. NORRIS$^2$

$^1$BSES Limited, Bundaberg, Queensland, Australia
$^2$Agricultural Engineering Consultant, Booker-Tate, Thames, UK
(formerly of BSES Limited)
rdavis@bses.org.au

KEYWORDS: Chopper Harvester Feeding, Forward-Feeding Zone,
Green Cane, High-Speed Film.

Abstract

CURRENT models of sugar cane chopper harvesters are affected by glut/starve situations for
gathering and feeding of cane. The gathering system, including the forward-feeding zone
(knockdown and finned rollers and the basecutters) and the setup of feed-train rollers, are
areas indicated for improved performance. Alternative concepts were developed to improve
the functionality of the gathering system and feed-train elements. However, there remains a
lack of understanding of the interactions occurring between the machine components and cane
in the forward-feeding zone during gathering, feeding, basecutting and buttlifting. The
interaction of these components with the cane needs to be fully understood to address the
issues of feeding, including minimum knockdown angle for butt-first feeding, control of cane
for active feeding, and minimising dirt intake. A novel approach was developed to modify an
existing harvester to allow alternative forward-feeding systems to be fitted and tested under
identical conditions. Modifications to the front end allowed incorporation of any forward-
feeding layout by fitting a choice of specially manufactured modules. Two modules were
developed, which incorporated leg and underslung basecutter configurations. Each module,
when installed, allowed the harvester to be operated as a fully functional harvester. Evaluation
of modules was supported by instrumentation, including high-speed cine film and data
acquisition of loadings on components to characterise the flow of cane. Comparative trials
under varying crop conditions benchmarked the flow of cane through the leg basecutter and
underslung basecutter modules. The flexibility of the modular format enabled enhanced
forward-feeding geometries to be evaluated and quantified using identical harvester
extractor/chopper/extractor configurations. Importantly, the modules were fully evaluated in
the field under commercial conditions. The functionality and performance of the harvester has
demonstrated that the system is extremely flexible and offers a powerful research facility for
evaluating the performance of harvester feeding systems worldwide.

Introduction

The proportion of the crop harvested without prior burning is increasing in most Australian cane
growing areas and throughout the world, due to a combination of economic and environmental pressures.
The move to green-cane harvesting is not without problems. Apart from the agronomic issues, machine
performance, particularly where larger crops are encountered, can be a major problem (Schembri and

Typically crops that are large, sprawled and tangled are very difficult for current harvesters to
successfully harvest at commercially acceptable rates and at an acceptable level of performance. To
overcome these problems, manufacturers have increased engine power in harvesters. This increase and,
and hence, the power available to various systems including basecutters, feedrollers and choppers, has
improved to some extent the ability to process these larger crops at commercially acceptable rates.
However, it has brought to the forefront the fundamental issues relating to feeding performance.

The rise in levels of extraneous matter associated with higher pour rates, particularly under
difficult feed conditions, affects sugar quality (Whiting and Norris, 2001). In addition, billet quality
declines, and there is an increase in losses associated with the gathering, basecutting and billeting processes, along with damage to the cane and the cane stool during the gathering and feeding of larger green crops.

**Background**

Schembri and Garson (1996) identified that harvesters typically operate in a glut/starve feed pattern. That is, the cane feeds in gluts followed by a gap in the feed after the glut passes through the machine.

Further research was undertaken by Davis and Norris (2000) to identify and quantify the mechanisms causing these conditions in heavy lodged green cane.

That research included the instrumentation of a 1995 specification Austoft 7000 harvester (representing an industry standard machine), with electronic data collection and video monitoring equipment.

The ZX11, a prototype harvester with alternative feeding concepts developed by Massey Ferguson in the early 1980s (Norris et al., 1998a), was installed with similar instrumentation, and comparative field trials were conducted in north Queensland and the Burdekin cane growing areas under a range of crop conditions.

That research identified the processes that occur during the feeding of cane into the harvester, and clearly demonstrated the magnitude of the problem in current machine designs (Norris et al., 1998b).

Initial results identified and quantified the mechanisms which cause inconsistent flow (glut/starve) of cane. These included:

- The gathering system in which spiral geometry, angle of inclination and dual spirals were all identified as critical parameters in optimising the gathering of lodged cane. There were clear opportunities for bridging of cane stalks during initial gathering (including interactions between the cane and the dual gathering spirals), and transfer of cane along the throat of the machine.
- The forward-feeding components (knockdown roller, finned roller, basecutters, buttlifter) and their ability to actively control and feed cane.
- The aggressiveness and synchronisation of the feed-train to ensure that the flow of cane is maintained into the feed system and presented evenly to the chopper system.

In addition to these issues, the knockdown of the cane by the finned roller adjacent to the basecutters, designed to induce the butt-first feeding of the cane into the feed-train caused considerable damage to standing cane stalks and the cane stool (Kroes and Harris, 1996).

Alternative machine design criteria to improve the functionality of these areas were devised. Concepts, which could be easily retrofitted onto current design harvesters, were developed and included a single-spiral gathering system.

Modifications to the feed-train elements were demonstrated to increase the feeding ability and increase billet quality. These developments have led to incremental increases in machine performance (Davis and Norris, 2000).

The layout of the forward-feeding zone on current design harvesters does not allow easy incorporation of retrofittable concepts that enhance the feeding performance. Therefore, while design concepts were devised, they were not evaluated in this initial work. Parallel to this work were the design and development of the BSES high-density harvester.

This development allowed the incorporation of alternative forward-feeding design concepts to be incorporated into its design (Norris and Davis, 2001).

While a higher level of feeding was achieved, the machine’s performance highlighted significant deficiencies in the knowledge of the interactions between the forward-feeding components and the cane during gathering and feeding.

The interaction of the forward-feeding components and the cane during gathering and feeding needs to be fully understood to address issues including minimum knockdown angle to achieve reliable butt-first feed, even feeding, control of cane after severing by the basecutters, minimising dirt intake, and the lifting into and the stratification of material up the feed-train.

Understanding these issues is paramount to underpinning improvement in current machine performance and for the development of improved machine designs. The standard harvester’s forward-feeding zone and inherent components is shown in Figure 1.
The research aimed at developing a full understanding of the interactions between the forward-feeding zone components of current harvesters and the cane during harvesting, and developing alternative design concepts. This would be achieved via the development of a research facility that would allow the processes to be identified and quantified.

Development of a test facility

The principal guidelines were to allow use of the dedicated instrumentation and analysis systems and to allow easy modifications to the geometry in the forward-feeding zone, while fully representing a standard harvester. Initially, it was planned to use the instrumentation and high-speed camera with a standard harvester. Limitations with this approach included constraints with the machine layout in the forward-feeding zone, particularly the mainframe and fuel tank, steering system, wheels/tracks and hydraulic circuitry. The concept of the forward-feeding module was devised to overcome the limitations with this approach. This approach incorporates the complete forward-feeding zone in a discrete module, which is then installed on the harvester. When installed, the harvester is operated as a fully functional machine.

Additional features with this concept include the ease of incorporating alternative forward-feeding geometries within a dedicated module, and rapid change of modules allows replicated field trials on the varying configurations to be conducted.

Harvester modifications

To minimise costs, a 1989 model Austoft 7000 harvester suitable only for wrecking was acquired. The harvester was stripped of all components to allow mainframe modifications and rebuilding.

Modifications to the harvester included:

Removal of original fuel tank

The location of the fuel tank was directly over the forward-feeding zone. This constrained the positioning of components and limited design geometries for alternative layouts. Repositioning the tank overcame these constraints, while allowing the void to accommodate the high-speed camera and associated lighting. This provided protection of the camera equipment and an optimum viewing window across the forward-feeding zone. Another fuel tank with a capacity of 200 L was fabricated and positioned underneath the engine bay.
Updated feed-train sidewalls
The layout of the feed-train forward of the second bottom feed roller was updated from the original 1989 model layout to a 2000 production model layout.

Mainframe design
The mainframe was stiffened and a subframe incorporated across the front of the existing mainframe to accommodate external support legs and provide attachment points for the forward-feeding module. After these alterations, the mechanical components were reinstalled and the machine rebuilt. The harvester incorporates standard horizontal arm primary and secondary extractors, a 12-inch differential chopper system, and feed rollers.

The development of the test harvester undergoing mainframe modifications is shown in Figure 2.

Fig. 2—Modifications to the harvester included sidewalls, mainframe and external support legs.

Module design
The modules were designed and fabricated as discrete, stand-alone units and resemble the front end of a harvester. The standard module is based on a 2000 production model 7000 front-end layout. The module incorporates the basecutter lift and suspension system, front wheels, sidewalls and feeding rollers and associated hydraulic components. The gathering spirals attach directly to the forward-feeding module.

Two modules based on the Australian industry’s standard cane harvester design were fabricated. This included an underslung basecutter forward-feeding configuration (Figure 3) and a leg basecutter forward-feeding configuration.

Each module will perform exactly as the machine it simulates, as all components replicate the positions and configurations on the standard harvester. Each module, when installed, allows the harvester to be operated as a fully functional harvester. This allows the feeding patterns of both configurations to be quantified.

Hydraulic setup
The harvester hydraulic system was not set up as in a standard production harvester. Modifications included separating the modules (gathering and forward-feeding), basecutters and feed-train/choppers into three discrete closed-loop circuits. These circuits were driven by high-pressure variable-displacement hydraulic pumps to give variable speed of these respective components and provide maximum hydraulic performance and efficiency.
Pressure and return-line connections are made with quick connect coupling. This system allows quick attachment of the module hydraulic plumbing when setting up on the harvester. The feed roller train and chopper system were optimised as per BSES specifications.

Instrumentation
The crop-handling areas of the harvester were instrumented with sensors to allow measurement of hydraulic pressure, feed roller displacement, and ground speed. This allowed loadings on the various components to be monitored during harvesting to investigate their performance and limitations during harvesting.

The high-speed data acquisition was set up on a laptop computer, for compactness and portability. The sensors included pressure transmitters for measuring hydraulic pressure, a radar unit for measuring ground speed, and rotary potentiometers for measurement of feed roller displacement.

The operation of the computer board is controlled by proprietary Windows-based software DASYLab® which allows the acquired data to be recorded directly to specified files.

High-speed cine photography
The capture of the cane flow pattern of and into the machine was beyond the capability of conventional video and camera technology due to the high flow rate of material moving through the forward-feeding zone. A LOCAM II 16 mm high-speed motion analysis cine camera and halogen lighting were utilised to capture this process at a recording rate of 450 frames per second.

The LOCAM II camera was used because of its ease of use, portability and power requirements. The camera was mounted inside the original fuel tank to give maximum flexibility in terms of field of component viewing. The camera was orientated to focus on material flowing across the basecutters and into the feed-train. This mounting location gives maximum flexibility in fields of view, allowing capture of the flow of material into the harvester and component/cane interactions.

Results
Field evaluation and comparative trials were undertaken during the 2001 Bundaberg harvesting season. Initial trials involved benchmarking the harvester when set up as standard.
The harvester was set up with the underslung module and fitted with the standard dual counter-rotating gathering system. The gathering spirals, knockdown roller and finned roller, were operating at the standard factory-set speeds of 195, 100 and 78 rpm, respectively. The only variation from factory standard was the synchronisation of the chopper/feed-train roller speeds.

Initial field trials to benchmark the performance of this setup were undertaken in two crop conditions, standing and lodged sugarcane variety Q170 yielding approximately 100 and 125 t/ha, respectively. The crop was harvested green.

In addition, two knockdown roller positions were evaluated in both crop conditions and three replications of each were undertaken. Trials were undertaken at an average ground speed of 5 km/h.

Figure 4 illustrates the hydraulic loading on the components in the standard underslung forward-feeding module when harvesting the erect and lodged crops.

During harvesting of the erect crop, the pressure loadings across the gathering spirals are relatively even, as expected; as the cane is standing and already aligned.

The pressure loading on the knockdown roller is relatively even and contrasts with that measured across the finned roller, where a more uneven load is occurring. This illustrates that the knockdown roller is contributing little to the active feeding of material.

The pressure loading on the finned roller indicates that more work is being done by this roller and is constantly feeding material. When harvesting lodged cane, the loadings increase and become more erratic.

Figure 5 illustrates the resulting displacement of the first and last top feed rollers during the identical time period as Figure 4.

The displacements of both rollers illustrate a smoother pattern with no cycling to the fully open or closed position. However, the harvester is processing more cane in the lodged crop. The displacement patterns indicate a very even flow through the harvester under both erect and lodged crop conditions.

The displacement pattern of the last top feed roller mimics closely the patterns of the first, but with a phase shift corresponding with the relative positions of the feed rollers.
These results illustrate that synchronising feed roller speeds improves the flow of material through the harvester via a more even feed of cane as it enters the feed-train.

A reduction in differential stalk separation and reduced baulking are plausible causes for the improved evenness of feed.

These results benchmark the typical flow patterns in erect and lodged crop conditions and reinforce the results found in previous research (Norris and Davis, 2002).

![Graph showing feed roller displacement](image)

**Fig. 5—First and last top feed roller displacement during identical time period as Figure 4.**

**High-speed filming**

Filming was undertaken of both the underslung basecutter and leg basecutter modules under similar crop conditions (and harvester operation). The leg basecutter gearbox posed a large obstacle when trying to view down across the basecutters. To overcome this obstruction for filming, the leg basecutter module fitted with the underslung basecutter was used. The slip rings on the underslung discs were replaced with false legs to represent the legs of the leg basecutter. These false legs were fabricated to the identical physical size as leg basecutter legs.

The resulting video showed contrasting feeding patterns between the two modules.

**Underslung basecutter module**

This setup was characterised by a consistent flow of material. Stalks were orientated in the direction of travel and in two distinct streams. The majority of stalks were aligned between the centre and the outer edge of the disc on both discs, with a smaller number of stalks flowing over the centre of the gearbox.

Layering of material was evident with stalks and tops on top, with trash underneath, and the depth of material was even and consistent throughout. Baulking of stalks was evident with those stalks entering across the centre of the gearbox.

The impact of the buttlifter and chopper system could be seen, with stalks pulsating at the respective frequency.

The interaction between the fins on the finned roller and cane was evident, with the fins actively maintaining alignment of stalks. Additionally, the finned roller controlled the depth of cane via its location in the forward-feeding layout.
Leg basecutter module

This setup was characterised by the agitated flow of material. The depth of material over the basecutters was increased due to a lack of constraint by the finned roller. The alignment of stalks was disorderly, with the majority of stalks moving across the basecutters at an angle of approximately 45°. Few stalks were presented to the buttlifter parallel with the direction of travel and more frequent stalk baulking was evident than in the underslung module. An explanation was that the butts of the stalks were impacting the first top feed roller due to the depth of material.

From the analysis of the high-speed data, the finned roller has a significant negative impact on the flow of material into the feed-train. This initial phase of the research has resulted in a better understanding of the flow of material into the harvester.

Conclusions

This modular research harvester was demonstrated to be an extremely flexible and powerful test platform. Each module, when installed, allowed the harvester to be operated as a fully functional harvester.

The modular format provided flexibility, with capacity for development of evaluation and quantification of module geometries using identical harvester extractor/chopper setups. In addition, alternative forward-feeding designs suitable for harvesting dual-row planting systems can now be developed and evaluated. Key considerations in the design of the modules included the need for identical representation of current model harvester layouts and requirement to achieve rapid module changes to allow replicated field trials on the performance of different machine configurations to be conducted in a relatively short period.

This approach and the resulting functionality and performance of the harvester have demonstrated that it is the most versatile test platform for researching the performance of harvester feeding systems. This research harvester offers very high levels of flexibility in component layout and has provided novel data on the main flow of cane into harvesters.

Acknowledgments

The authors thank BSES technical assistants Phillip Netz and John Wilson for their input into the development and substantial task of fabricating the system. Thanks go to Mal Baker and Don Helmrich at CNH Austoft for supply of components and access to laser cutting equipment. Funding for this activity was provided by the sugar industry and the Commonwealth Government through the Sugar Research and Development Corporation and is gratefully acknowledged.

REFERENCES


UNE ETUDE DES CARACTEREISTIQUES D’ALIMENTATION DE L’AVANT DES COUPEUSES EN CANNES TRONCONNEES: DEVELOPPEMENT D’UNE COUPEUSE POUR LA RECHERCHE

R.J. DAVIS\(^1\) et C.P. NORRIS\(^2\)

\(^1\)BSES Limited, Bundaberg, Queensland, Australia
\(^2\)Agricultural Engineering Consultant, Booker-Tate, Thames, UK.
(formerly of BSES Limited)
rdavis@bses.org.au

MOT-CLES: Alimentation des Coupeuses a Cannes Tronçonnées, Zone d’Alimentation a l’Avant, Cannes Vertes, Film Rapide.

Résumé

LES MODELES courants de coupeuses a cannes tronçonnées sont affectés par une alimentation saccadée. Le système de ramassage comprenant la zone des organes d’alimentation (rouleaux et disques de coupe) et les rouleaux d’alimentation sont les parties aptes à être améliorées. Différents concepts furent développés afin d’améliorer le fonctionnement des dispositifs de relevage et du train d’alimentation. Toutefois, les interactions entre les composantes de la machine et la canne dans la zone d’alimentation pendant le ramassage, l’alimentation, la coupe à la base et le relevage ne sont pas encore totalement comprises. Ces interactions doivent être totalement comprises pour étudier les paramètres d’alimentation, tels l’angle de rabattage minimal pour la présentation du bas des tiges, le contrôle de la canne pour une alimentation dynamique et pour minimiser la prise de matières étrangères. Une approche novatrice fut développée pour la modification d’une coupeuse afin de permettre le montage et la comparaison de différents systèmes d’alimentation dans des conditions identiques. Ces modifications ont permis l’incorporation de différents modules comprenant des configurations ‘leg base’ et ‘underslung’ des disques de coupe. Les modules furent évalués à l’aide de films rapides et d’acquisition électronique des charges sur les composantes. Des essais comparatifs dans des rendements différents ont établoncé le flux de la canne à travers les deux configurations de disques de coupe. La flexibilité du système de modules a permis l’évaluation et la quantification des configurations d’alimentation pour des réglages identiques de l’extracteur primaire et des tronçonneuses. L’aspect le plus important a été l’évaluation des modules au champ dans des conditions industrielles. La functionalité et la performance de la coupeuse a démontré que le système est très flexible et qu’il offre des facilités de recherche pour l’évaluation de la performance de différents systèmes d’alimentation des coupeuses à travers le monde.
UNA INVESTIGACIÓN DE LAS CARACTERÍSTICAS DE ALIMENTACIÓN DE LA ZONA DE ALIMENTACIÓN DELANTERA DE COSECHADORES: DESARROLLO DE UN COSECHADOR DE INVESTIGACIÓN

R.J. DAVIS1 y C.P. NORRIS2

1 BSES Limited, Bundaberg, Queensland, Australia
2 Agricultural Engineering Consultant, Booker-Tate, Thames, UK.
(formerly of BSES Limited)
rdavis@bses.org.au

PALABRAS CLAVES: Alimentación de Cosechador, Zona de Alimentación Delantera, Caña Verde, Película de Gran Velocidad.

Resumen

Los actuales modelos de cosechadores de caña de azúcar son afectados por las situaciones de super-abundancia / escasez para recolección y alimentación de caña. El sistema de recolección, incluso la zona de alimentación delantera (el derribo y los rodillos de aletas y los cortadores de base) y la configuración de rodillos del tren de alimentación, son áreas indicadas para mejora de desempeño. Se desarrollaron conceptos alternativos para mejorar la funcionalidad del sistema de recolección y los elementos del tren de alimentación. Sin embargo, aún hay una falta de comprensión de las interacciones que ocurren entre los componentes de la máquina y la caña, en la zona de alimentación delantera durante la recolección, alimentación, corte de base, y levantamiento de tallos. La interacción de estos componentes con la caña necesita ser entendida completamente, para abordar los problemas de alimentación, incluso el ángulo de derribo mínimo, para alimentación con el tallo primero, el control de caña para alimentación activa, y la minimización de la entrada de suciedad. Un nuevo abordaje fue desarrollado para modificar una cosechadora existente, para permitir encajar los sistemas de alimentación delantera alternativos y probarlos bajo condiciones idénticas. Las modificaciones en la extremidad delantera permitieron la incorporación de cualquier tipo de alimentación delantera, al instalar una opción de módulos especialmente manufacturados. Se desarrollaron dos módulos que incorporaron configuraciones de pieña y de cortador de base suspendido. Cada módulo, cuando instalado, le permitió a la segadora ser operada funcionalmente. La evaluación de módulos tuvo apoyo de instrumentación, incluyendo film cinematográfico de gran velocidad y adquisición de datos de cargas en los componentes, para caracterizar el flujo de caña. Los ensayos comparativos en condiciones variables de cosecha variante establecieron comparaciones del flujo de caña, a través de los cortadores de base y los módulos cortadores de base suspendidos. La flexibilidad de formato modular permitió evaluar las geometrías mejoradas de la alimentación delantera y hacer cuantificaciones usando configuraciones de extractor/cortador/extractor de segador idénticas. Hay que destacar que, los módulos se evaluaron totalmente en trabajo de campo, bajo condiciones productivas normales. La funcionalidad y el desempeño del segador demostraron que el sistema es sumamente flexible y ofrece una capacidad de investigación poderosa, para evaluar el desempeño de sistemas de alimentación de segador mundialmente.