THE USE OF HARVESTING SYSTEMS AND LABOURER PLATFORMS IN THE SOUTH AFRICAN DECIDUOUS FRUIT INDUSTRY

by
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DECLARATION

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SUMMARY

The impact of harvesting systems and laborer platforms on fruit quality were assessed when harvesting, as well as laborer productivity when performing orchard actions requiring the use of ladders. Harvesting systems and laborer platforms were compared to conventional labor practices. Trials were done on stone and pome fruit farms throughout the Western Cape.

Harvesting systems showed potential to decrease bruising on hardy apple cultivars such as Red Chief and Cripps' Red. However, similar or even higher injury levels were obtained on more sensitive cultivars such as Golden Delicious and Cripps' Pink. Conventional teams incur little bruising on the hardier cultivars, thus the scope of improvement on these cultivars is small. Conventional teams incur higher injury levels on more sensitive cultivars, leaving much room for improvement. However, due to high harvesting injury levels incurred by teams on the harvesting systems, no improvement was obtained.

Conventional teams achieve very high picking productivity outputs for hardy cultivars like Abate Fetel, Red Chief and Cripps' Red whereas outputs are lower for sensitive cultivars like Golden Delicious and Cripps' Pink. Harvesting systems reached an upper limit of around 150 kg per picker per hour when strip picking, regardless of cultivar hardiness. This limit stemmed from the misalignment between orchard and machine design, which results in a very inefficient picking action. This limits the number of picking cycles that can be completed in a certain amount of time, which in turn limits the weight of fruit that can be picked in that time. Furthermore, factors such as tree size, shape and uniformity, fruit distribution on the tree, fruit size and quality, orchard floor condition and aspect, labor team dynamics, harvesting incentives, bin condition, operational system employed and harvest logistics all affected the overall productivity and efficiency of the harvesting systems.

When performing summer pruning with the aid of a laborer platform, productivity was substantially increased compared to conventional laborers on ladders. Dormant pruning and fruit thinning with laborer platforms also showed potential for increased laborer productivity. The extent of improvement was smaller than for summer pruning and was dependent on the pruning/ thinning strategy employed as well as tree architecture. In general, narrower and younger trees showed larger increases in productivity. Producers should aim to simplify pruning and thinning strategies in order

to maximize productivity gains when using laborer platforms while at the same time maintaining good fruit quality and yield.

Our study revealed that laborer platforms can increase laborer productivity for certain orchard tasks but substantial gains in harvesting productivity through mechanization is not a possibility in the near future. Our study did, however, allude to the potential gains in productivity that can be made with more efficient management and implementation of conventional harvesting practices. Producing, and more specifically, harvesting deciduous fruit for the fresh market will likely remain a labor intensive process. Therefore it is important that producers focus on investing in labor-related factors such as laborer training, motivation and satisfaction together with the careful implementation of new technologies such as laborer platforms.

OPSOMMING

Die impak van oesstelsels en arbeider-platforms op vrugkwaliteit tydens oes sowel as arbeider produktiwiteit met die uitvoer van boordtake waar traplere gebruik word, is geevalueer. Die oesstelsels en arbeider-platforms is vergelyk met konvensionele praktyke wat op verskeie steen- en kernvrugplase in die Wes-Kaap gebruik word.

Oesstelsels het die potensiaal om appel kultivars met ŉ lae beseringsgevoeligheid, soos Red Chief en Cripps' Red minder te kneus. Soortgelyke of selfs hoër vlakke van oesbeserings is waargeneem op sensitiewe kultivars soos Golden Delicious en Cripps' Pink. Konvensionele plukspanne handhaaf oor die algemeen lae vlakke van oesbeserings op geharde kultivars, wat min ruimte vir verbetering laat. Oesbeserings vir konvensionele spanne op sensitiewe kultivars is egter hoog en laat baie ruimte vir verbetering, maar weens die hoë vlakke van beserings van die spanne op die oesstelsels, is geen verbetering waargeneem nie.

Konvensionele plukspanne handhaaf hoë oesproduktiwiteit uitsette op geharde kultivars soos Abate Fetel, Red Chief en Cripps' Red terwyl oesproduktiwiteit vir sensitiewe kultivars soos Golden Delicious en Cripps' Pink laer is. Oesstelsels het ŉ maksimum plukuitset van 150 kg per plukker per uur behaal tydens skoon-pluk, ongeag kultivar gehardheid. Hierdie beperking ontstaan as gevolg van die onverenigbaarheid tussen boord- en masjienontwerp wat tot ŉ baie ondoeltreffende pluk-aksie lei vir die plukkers. Die onverenigbaarheid beperk die aantal plukbewegings wat ŉ plukker kan voltooi binne ŉ sekere tyd wat weer die totale massa van die vrugte wat in daardie tyd gepluk word beperk. Boomgrootte, -vorm en –uniformiteit, vrugverspreiding op die boom, vruggrootte en –kwaliteit, toestand en helling van die boordvloer, arbeiderverhoudings, plukker vergoeding, krattoestand, operasionele stelsels wat geïmplementeer word en die organisering van oestyd logistiek het ŉ invloed gehad op die produktiwiteit uitsette wat met die oesstelsels behaal is.

Die gebruik van ŉ arbeider-platform vir somersnoei het arbeider produktiwiteit beduidend verhoog in vergelyking met konvensionele arbeiders op traplere. Wintersnoei en vruguitdunning met arbeider-platforms het ook die potensiaal om arbeider produktiwiteit te verhoog. ŉ Kleiner verhoging in produktiwiteit as by somersnoei is waargeneem en het afgehang van die snoei- of uitdun-strategie sowel as boom argitektuur. Oor die algemeen het jonger en smaller bome groter verhogings in produktiwiteit getoon. Ten einde maksimum voordeel te geniet met die gebruik van arbeider-platforms moet produsente poog om snoei- en uitdun-strategieë te vereenvoudig terwyl goeie vrugkwaliteit en opbrengs gehandhaaf word.

Ons navorsing het getoon dat die gebruik van arbeider-platforms, arbeider produktiwiteit vir sekere boord-take kan verhoog, maar ŉ beduidende toename in oesproduktiwiteit d.m.v. meganisasie blyk nie ŉ moontlikheid te wees in die nabye toekoms nie. Ons navorsing het wel gedui op die potensiële toenames in oesproduktiwiteit wat verkry kan word met meer doeltreffende bestuur en implementering van huidige konvensionele stelsels. Die verbou, en meer spesifiek die oes van sagtevrugte vir die varsproduktemark sal waarskynlik ŉ arbeidsintensiewe proses bly. Daarom is dit belangrik dat produsente aandag gee aan die opleiding, motivering en bevrediging van arbeiders saam met die implementering van nuwe tegnologie soos arbeider-platforms.

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GENERAL INTRODUCTION

The 2011 Research Strategy document of HORTGRO Science identifies the cost-price squeeze farmers are experiencing as a threat to sustainable fruit farming (Steyn and Brink, 2012). Furthermore, some producers are also expressing concerns about the future availability of capable and willing labor to carry around heavy ladders on fruit farms (Steenkamp, 2014). A mechanization assessment study conducted by the Dutoit Agri Group and Southtrade Pty (Ltd) (Agricultural machinery supplier, Brackenfell, South Africa) highlighted the need for more industry level research to be done with regard to the implementation of harvesting systems and laborer platforms on South African deciduous fruit farms (Steyn and Brink, 2012). The South African Apple and Pear Producers Association (SAAPPA) board requested HORTGRO Science to submit an industry project to evaluate harvesting systems and laborer platforms under South African conditions. HORTGRO Science acquired a Hermes Tecno L™ harvesting system, which was evaluated together with a privately owned harvesting system and laborer platforms as well as with machines borrowed from Southtrade. The widespread labor unrest in the Western Cape agricultural sector in November 2012 and the resultant ca. 50% increase in the minimum wage (SABC, 2012; Thomas, 2012), generated more interest in the already up and running project from producers' side. The aim of the study was to determine how the use of harvesting systems and platforms could decrease input costs, increase fruit quality and increase profitability for South African deciduous fruit producers. We wanted to determine the realistic potential of these machines in various orchard and management practices and identify the changes that we would need to make to facilitate automation in the orchard.

The literature study gives a brief history of past agricultural mechanization and the difference between mechanization of fresh market deciduous fruit farming and other agricultural crops. It also discusses the reasons why South African deciduous fruit producers are considering mechanizing certain aspects of production. Furthermore it provides a review of international research that has been done on harvesting systems and laborer platforms. Various available platforms and harvesting systems were investigated on the basis of the level of productivity and efficiency achieved with these machines as well as the circumstances under which and the methods by which it was measured. Lastly, the literature study assessed international trends with regard to establishment of new orchards with mechanization in mind.

Data form commercial packhouses in the major Western Cape fruit production areas show that harvesting related injuries on apples for the 2013/2014 season ranged from 10.7% to 13.6%, with a five year average of 12.6%, whereas for pears it was approximately 7.0% for the 2013/14 season, with a five year average of 8.3%. Using 2013 injury levels and prices from HORTGRO (2013), with the assumption that all of the injured fruit were export quality fruit downgraded to processing grade quality. For apples this translates into a loss in revenue of R986 million (R1 087 per ton) of which R129 million (R143 per ton) can be salvaged by sending the fruit for processing. For pears it means a loss in revenue of R279 million (R735 per ton) of which R42 million (R110 per ton) is salvageable. These figures highlight the importance of minimizing injuries incurred at harvest time. Therefore the main focus of our study was on the impact of harvesting systems on harvest related fruit injuries. We aimed to determine whether the harvesting systems can consistently and substantially decrease injuries incurred at harvest time compared to conventional harvesting practices. Furthermore, some producers are also interested in using harvesting machines in order to decrease the indirect losses incurred when fruit are dropped during harvest or damaged on the tree (E. Heydenrych, Personal communication). Their concern is that when pickers are selectively picking, the placement of ladders can damage fruit left on the tree to ripen further or even knock it off the tree. If one export quality apple is dropped or damaged per tree with trees planted at 1667 per ha, it translates into a potential revenue loss of R1500 per ha (HORTGRO, 2013). This issue was incorporated into three of the trials in our study. The aim was to determine whether the elimination of ladder movement through the orchard and into trees during harvesting would decrease the number of dropped fruits when harvesting with harvesting systems.

In the United States of America, labor accounts for 50 to 58% of allocable variable production costs on fruit farms (Calvin and Martin, 2010; West et al., 2012). In South Africa in 2012, labor accounted for 33 to 34% of allocable variable cost on fruit farms (HORTGRO, 2013; Meyer et al., 2012). For the period 2003 to 2012, the nominal cost of intermediate farming goods increased by 154% (Directorate Statistics and Economic Analysis, 2013) and minimum wage by 88% (HORTGRO, 2013). When taking the 2012/13 minimum wage increase into account, the nominal minimum wage increased by 184% (HORTGRO, 2013) whereas producer prices for fruit only increased by 86% (Directorate Statistics and Economic Analysis, 2013). This highlights the need for more labor efficient fruit production processes on deciduous fruit farms. Our study on the effect of harvesting systems and laborer platforms on harvesting, pruning and thinning productivity sought to quantify the potential of harvesting systems and laborer platforms to increase laborer productivity. We wanted to determine the underlying factors that influence the level of productivity and efficiency achieved with such machinery, as well as what producers stand to do in the case of unsuitable existing orchards and –harvest operations. It is however important to keep in mind that labor is only part of the total cost of production and producers should continuously seek ways to reduce other factors of production or compensate by increasing yield with or without mechanization (Van Zyl et al., 1987). This study then also attempted to determine the role harvesting systems and laborer platforms can play as an additional tool for the South African deciduous fruit industry in its current state as well as the near future.

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LITERATURE REVIEW

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1. Introduction

In the past, agricultural mechanization coincided with the major replacement of laborers by machinery, e.g. the introduction of combine harvesters (Simbi and Aliber, 2000; Van Zyl et al., 1987). This was also seen in the wine grape industry with the earliest mechanical grape harvesters harvesting three to six tons per hour, translating into a replacement of 17 laborers per machine (Shepardson et al., 1970). Mechanization of this sort has been criticized for intensifying rural unemployment and for creating adverse social effects in rural communities (Rijk, 1999; Van Zyl et al., 1987). Although mechanization in South African agriculture has shown the same trends as in many developed countries, the driving forces behind these trends differed between these countries and South Africa (Simbi and Aliber, 2000).

According to Simbi and Aliber (2000) the labor shedding and mechanization in South African agriculture up until the year 2000 was largely driven by non-economic factors such as the fear of losing control of farms due to legislation and the labor force becoming more difficult to manage because of laborers having more power than prior to 1994. The government and farmers saw farm laborers as a problem and mechanization was seen as a method of dealing with troublesome laborers (Schirmer, 2004; Simbi and Aliber, 2000). Further evidence that past mechanization was not solely based on economic grounds is the rapid implementation of tractors and combine harvesters in the wheat and maize industries and the replacement of laborers by chemical weed killers and piped irrigation systems in the citrus and wine industry during the 1970's (Schirmer, 2004). From 1970 to 1975 unemployment amongst rural black job seekers increased from 25 000 to 315 000 (Schirmer, 2004). This led to an oversupply of labor which decreased the price of labor relative to that of scarce capital. However this cheapening of labor did not influence the rate of mechanization, suggesting that producers were predisposed to mechanize (Schirmer, 2004). Due to government policy and regulation farmers did not consider competitive measures that would have led to the most efficient allocation of resources with regard to mechanization and improvement in productivity was not the primary driving force (Schirmer, 2004; Van Zyl et al., 1987).

With regard to the deciduous fruit industry, limited progress has been made in terms of mechanizing the production of fresh market fruit (Rudkin et al., 1973; Sarig, 2005). The technology currently available will not lead to a total replacement of laborers as in the abovementioned examples of mechanization in the agricultural industry and it is unlikely that machinery will be able to replace the skills of workers in the near future (Calvin and Martin, 2010; Robinson and Sazo, 2013). According to Sazo et al. (2010) and Sazo and Robinson (2013), European farmers have been partially mechanizing their orchards for the past five decades, with South Tyrol in Italy being one of the few regions where growers have successfully incorporated platforms in the whole apple production process. The successful implementation of platforms could, however, lead to the loss of unskilled jobs while potentially creating jobs that demand a higher skill level with higher wages (Peterson, 2006). In addition to this, many countries that are seeking ways to mechanize their fruit industry are already experiencing shortages of laborers (Peterson, 2005b; Schupp et al., 2011) and in these situations partial mechanization has the potential to expand the labor pool by enabling conventionally unsuited individuals to perform orchard tasks at rates comparable or faster than that of conventional methods (Elkins et al., 2010; Sazo et al., 2010).

Mechanization is one of three responses farmers have to rising labor costs, with the other two being to use less labor by adapting farming practices and to use labor more efficiently by keeping strategic and management practices up to date (Calvin and Martin, 2010). Seeing that labor costs are only part of the total cost of production (Van Zyl et al., 1987), producers can also seek ways to reduce any of the other factors of production or compensate by increasing yield with or without mechanization. Methods of achieving this include precision farming, better irrigation practices and pest control as well as improvements in cultivars (Calvin and Martin, 2010). It is, however, important to note that the scope and methods a certain producer avails of to offset increasing production costs, is dependent on the current level of performance of individual activities on the farm as well as the performance of the farm as a whole. Therefore it is important for deciduous fruit producers to determine to what extent certain orchard tasks can be mechanized as well as to mechanize with concomitant advancements in farming practices and management.

2. Factors causing deciduous fruit farmers to explore mechanization as an option

2.1. Cost of production

Figure 1 shows that since 2007 the cost of production has increased at a much faster rate than the price that South African fruit farmers receive for their produce. Farmers are price takers and therefore are unable to pass rising production costs on to the next role player and this forces them to find ways of producing more efficiently (Peterson, 2006). If farmers cannot keep up with the uncontrolled increase in total cost of production, they may lose market share to more competitive producers (Calvin and Martin, 2010).

Labor accounts for half the variable production costs for USA vegetable and fruit farms (Calvin and Martin, 2010). For the typical USA apple farm, labor accounts for 58% of variable production costs with pruning and training accounting for 25% of variable labor cost, thinning for 21% and harvesting for 44% (West et al., 2012). In South Africa in 2012, labor accounted for 33% of variable production cost with pruning, thinning and training accounting for 50% and harvesting for the other 50% of variable labor cost on apple farms (HORTGRO, 2012). In South Africa in 2013, labor accounted for 45% of variable production cost with pruning, thinning and training accounting for 61% and harvesting for the other 39% of variable labor cost on apple farms (HORTGRO, 2013). Meyer et al. (2012) shows that on the typical apple and pear farm in South Africa, casual labor accounts for 34% of directly allocable variable cost.

2.2. Labor related factors

The seasonal nature of deciduous fruit farming creates a seasonal demand in labor on deciduous fruit farms. The peak demand for labor is during harvest time (Schupp et al., 2011). According to Schupp et al. (2011), fruit growers in developed countries are facing a shortage in labor supply together with high costs of production and increasing competitiveness in the global market for their produce. This shortage stems from the fact that labor dependent farms compete with more lucrative urban sector wages (Sarig, 2005). A shortage of labor makes producers more vulnerable to adverse weather conditions during the harvest season, which can result in financial losses (McFerson, 2011). The shortage of labor is primarily caused by a workforce unwilling to do hard physical labor on farms and in orchards when they can earn more money in other jobs (Sarig, 2005). In the USA, this has led to the employment of large numbers of Hispanic workers who are willing to work in the orchards, but strict state legislation regarding the employment of immigrants is limiting the number of allowed immigrants (McFerson, 2011). Modern farming practices contribute partly to labor shortages and accentuate shortages already present due to higher density plantings with higher yields requiring more labor per hectare if tasks are performed the conventional way (Sazo et al., 2010). Some producers believe the solution lies in attracting a strong, productive work force by creating an efficient and productive work environment that maximize worker remuneration (Warner, 2008).

The situation in the South African deciduous fruit industry differs somewhat from the descriptions of researchers of industries in more developed countries. Kritzinger et al. (2004) state that the global integration of export fruit markets and the deregulation of the South African deciduous fruit sector in 1997 have increased the global and local competition South African producers are facing. This has given large supermarket buyers the opportunity to set high technical, environmental and employment requirements for producers to adhere to. Furthermore, after apartheid political advancements have led to more strict labor legislation regarding the employment of laborers in agriculture. The culminating effect of the abovementioned was the externalization of farm labor to a large extent. This entailed a move away from permanent on-farm labor towards off-farm contract workers as well as on-farm seasonal workers. This shift enabled producers to reduce labor costs, avoid certain legislative aspects and adapt employment of labor as needed. On the other hand this has led to laborers being very mobile between farms and other jobs. Thus producers struggle to employ a stable, committed labor force throughout the season and also from season to season. It is ironic that this volatility in the labor force stems directly from the experience of contract laborers that they have little job security. South African producers are thus considering the substitution of laborers with machines in order to reduce production costs and to avoid social problems stemming from large numbers of people living and working on the farm, overcrowded housing and stringent employment legislation as is mentioned by Kritzinger et al. (2004) and Simbi and Aliber (2000).

However, some producers are expressing concerns about the willingness and ability of the younger generation of unskilled laborers to work on fruit farms (Steenkamp, 2014). Therefore it might be worthwhile for South African producers to focus on attracting labor by creating a comfortable working environment with good team relations and worker remuneration to incentivize workers to be productive and efficient as Sazo et al. (2010) suggested for producers in developed countries.

2.3. Advantages and disadvantages of mechanization

There are several advantages associated with the use of laborer platforms, e.g. time and labor savings because inefficiencies such as climbing up and down ladders are eliminated when pruning, hand thinning, trellis building, leader selection, tree training, installation of mating disruption dispensers and harvesting; it encourages the same pace of work for the whole team, which could increase productivity if the faster workers motivate the slower workers; it decreases the chances of over/under pruning or hand thinning and physical exertion is reduced (Sazo and Robinson, 2013; Sazo et al., 2010). In the case of platforms lessening the demand for labor during harvest time, growers can potentially employ fewer employees, but on a more permanent basis (McMechan, 1968; Sarig, 2005), providing laborers a more secure source of income. However, it may also emphasize the seasonal nature in labor requirement for fruit farming if the platforms work better for orchard tasks such as pruning and thinning and does not lead to a significant gain in productivity when harvesting. Sazo and Robinson (2013) and Sazo et al. (2010) list the following disadvantages: An experienced operator and/or team leader is needed to keep a pace that will not lead to idle workers if it is too slow or over exertion if it is too fast; it is also very likely that the faster workers will be held back by the slower workers; when workers' productivity increase, the chance of repetitive motion injuries also increase. Furthermore the advanced technology of some platforms will require trained mechanics for routine maintenance and repairs (Sarig, 2005).

3. Discussion of available laborer platforms

Conventionally workers use ladders to perform tasks such as pruning, thinning, hormone-dispenser hanging, tree training and trellis construction, but in suitable orchards laborer platforms can replace the ladder in all of these tasks (Sazo and Robinson, 2013). In New York, the adoption of worker platforms came in the past ten years only after growers started planting high density orchards with narrow canopies such as the Tall Spindle system (Sazo and Robinson, 2013). There are various types of laborer platforms that differ in terms of simplicity, size, maneuverability and adjustability.

3.1. Single person positioners

Single person positioners ("Cherry pickers") have mainly been used for pruning in low to medium density orchards in New York (Sazo et al., 2010). The machines are usually self-propelled. The operator stands in a basket attached to a hydraulically operated boom from where he/she can adjust the height of the boom as well as steer the platform. The major drawback for these machines is the fact that they only replace a single ladder, making it very capital intensive with a drastic increase in productivity required in order to justify it.

3.2. Single- and multilevel self-propelled platforms

Different variations of single- and multilevel platforms are available and it is quite common to see producers building their own (McMechan, 1968; Sazo et al., 2010). These range from platforms built on truck chassis to self-steering, auto-levelling hydraulically controlled, multilevel platforms with independently adjustable levels. They also vary in terms of the number of workers they can carry, ranging from 4 to 16. In essence, all of them replace ladders and in a suitable orchard there would be very little difference in efficiency between the cheaper and the more expensive machines. The more expensive machines do, however, offer worker safety and comfort as well as adjustability features that the cheaper machines lack.

3.3. Tractor mounted and tractor pulled platforms

Tractor mounted or pulled platforms are cheaper than self-propelled machines and are also self-built (Sazo and Robinson, 2013). Tractor mounted, over the row platforms allow four workers to work on either sides of two independent rows at the same time with the tractor only having to go down every alternate row. By covering both sides of a row of trees it does not leave rows of trees that have only been worked on the one side as is the case with other platforms (Sazo and Robinson, 2013). The only difficulty is that in the absence of a dedicated driver the tractor must be controlled from the platform and not all tractors are suited for this (Sazo and Robinson, 2013).

4. A review of commercially available methods for harvesting of fresh market deciduous fruit

According to Sarig (2005) there are three categories of mechanized harvesting: Laborer platforms and harvesting systems that facilitate laborers in what they do; labor replacing machines such as mechanical mass removers that never made it into commercial use and robotic harvesters that are still in experimental phase.

4.1. Conventional type harvesting:

Conventional harvesting refers to harvesting methods that are currently being used on large scale in the South African deciduous fruit industry. All of these methods can broadly be classified into two main types of harvesting namely tractors with bin trailers and bin-on-the-ground-harvesting.

4.1.1. Tractors with bin trailers

Variations of tractors with bin trailers are used in different countries and production regions. It may entail a train of single-bin trailers hitched together behind a tractor (Peppelman et al., 2006) or it can be a combination of three-bin and two-bin trailers hitched behind a tractor (D. Havenga, personal communication). Pickers either harvest directly into the bin (Peppelman et al., 2006) or fruit can be picked into harvesting bags that are then emptied into the bins on the trailers. If necessary, sorting takes place at the bin with cull fruit placed into separate bins. Peppelman et al. (2006) report of trailers that have steps built onto them for pickers to stand on when harvesting the upper canopy fruit. This eliminates the need for ladders, but the orchard system and harvesting practices must be suitable, the tractor must drive down each row individually and trees must be small enough for the average picker to reach the fruit in the top of the tree. With larger picking teams with picking bags harvesting multiple rows at a time, the tractor does not have to drive down every row.

In South Africa a tractor with one three-bin trailer and two two-bin trailers are the most common. Picking teams vary in size and harvest multiple rows at a time. On some farms each picker has their own ladder and harvesting bag whilst on others there are dedicated ladder pickers and dedicated ground pickers. The norm is to have two tractor-and-bin-trailers combinations per team in order to keep the harvesting as continuous as possible. Tractors can either be parked in the tree row or in picking rows perpendicular to the tree rows. Pickers have to walk to and from the tractors and bin trailers to empty their bags.

4.1.2. Bin-on-the-ground

Bin-on-the-ground-harvesting is also used in many variations. In some cases bin trolleys are used to transport the bin up and down the rows following the pickers (Peppelman et al., 2006). A forklift or bin carrier or specialized bin trailer is used to transport empty bins into the row and to take full ones out. In some cases the forklift is used to move the bin up and down the row to keep up with the pickers (McMechan, 1968). Pickers can either work together in teams or individually to fill a bin. The idea is to minimize the distance walked by the pickers. This method of harvesting is less capital intensive than bin trailer harvesting.

4.2. Mobile laborer platforms:

When harvesting, pickers stand on top of the platform and harvest the upper canopy of the trees after a ground crew has harvested the lower canopy. Most platforms can pick up empty bins from the ground at the front and lower full bins back to the ground and put it down in the row behind the platform. Pickers can harvest directly into the bin or use harvesting bags. If necessary, sorting takes place on the platform, either by the pickers themselves or by a sorter on the platform.

4.3. Pneumatic type harvesting systems:

DBR Conveyor Concepts and Oxbo International Corporation are American companies that manufacture pneumatic type harvesting systems (DBR Conveyor Concepts, 2013; Oxbo Intl. Corp., 2014). Pickers place the harvested apples in flexible tubes that are either fixed on the guard rails of the platform or slung over the picker's shoulder. A suction pump creates a vacuum in the tubes that sucks the apples through the tubes to a decelerator that slows down the fruit before placement of apples in the bin by mechanical bin filler. This harvesting system can handle fruit with a round shape and a diameter less than that of the pipe. Varying fruit size may decrease the machine's efficiency because the fruit size determines the pressure difference inside the pipe, which in turn determines the speed at which fruit move through the pipe. Difficulties may be experienced with pears if they are not placed correctly into the pipe and peaches may lose their fuzz because of friction against the pipe wall.

The modular design of the DBR Conveyor Concepts harvesting system allows it to be used on various mechanical platforms (Schupp et al., 2011). Therefore, future upgrades can be done separately and will be economically more feasible. The system makes use of a dry decelerator to slow the fruit down as they exit the pipe. Earlier models could only accommodate two pickers (Schupp et al., 2011) with later models accommodating four pickers (Warner, 2012). Full bins are placed behind the platform in the row with empty bins being loaded from a straddle trailer pulled behind the platform (Schupp et al., 2011). Additional features include a self-levelling mechanism, LED lighting for harvesting at night and harnesses instead of safety rails to increase worker mobility.

The harvesting system developed by Oxbo International Corporation and Picker Technologies offers producers on-the-go sorting of fruit via an on-board computer and camera that keeps track of the number, size and quality of the fruit for each picker (McFerson, 2010). The machine automatically allocates cull fruit to a separate bin. The machine picks up empty bins at the front and discharges the full bins in the row. It uses a water filled decelerator with a different type of dry bin filler than the DBR harvesting system. It can only accommodate four pickers at a time and the harvesting system cannot be removed, which may limit the use of the machine as a laborer platform.

The fact that both machines can only accommodate four pickers might be a problem when harvesting taller trees as are typical for South African orchards. Furthermore, this leads to an immense capital expense per person that will deter farmers from purchasing it. Other concerns are the machine's ability to deal with varying fruit size and the handling of pears and peaches because many producers grow a wide range of fruit and it would make sense to have a machine that can deal efficiently with different types of fruit and varying sizes. With regard to orchard sorting capabilities, it depends on the requirements of the pack house for fruit delivered to them.

4.4. Conveyor type harvesting systems:

Mobile platforms fitted with conveyor type harvesting systems are the most common type of harvesting system used in Europe (Peterson, 2005a). Companies such as Zucal (Meccanica Zucal, Romeno, Italy) and Hermes (Hermes, Gargazonne, Italy) manufacture these types of machines in various sizes, but all of them rely on the same basic concept. The most common are multilevel platforms that can accommodate 4 to 8 workers. The harvesting system consists of a series of conveyor belts. Each picker has a small conveyor belt that can pivot around as well as hinge up and down allowing the picker to position it in the most desirable way. The picked fruit is placed on the small conveyor belt, which transports the fruit to a central conveyor belt on which the fruit is transported to the bin-filler, which then places the fruit in the bin. Once a bin is full, it is discharged behind the platform in the row where it is picked up by a forklift and transported to the loading bay. Empty bins are loaded from a bin trailer or picked up at the front of the platform and placed into the bin-filler. Sorting is done by the pickers or, if the machine allows it, by an extra worker standing next to the central conveyor belt. Cull fruit is put into a separate container that is fixed on the harvesting system or it may be a bin loaded on a platform on the front of the machine.

Van Doren Sales (2012) and (Peterson, 2005a) have developed similar conveyor type harvesting systems in separate research efforts (McFerson, 2010; Peterson, 2005a). Pickers harvest fruit into harvesting bags and then empty them onto two large conveyor belts, one positioned on top of the machine for the pickers on the platform and the other one at the front of the machine for the ground level pickers. The two conveyors converge at the sorting area where sorters remove the cull fruit. The bins move through the machine, with empty bins being picked up at the front and the full bins discharged in the row at the back. The machine is able to work in V-trellis systems where other platforms struggle to operate. The simpler design could potentially be a great advantage under South African conditions where the machine might have more than one operator, will be working under adverse conditions and on rough terrain and maintenance and repairs must be done on the farm and in limited time. The amount of pickers on the machine can be varied as the need arise because every picker harvest into his harvesting bag and can work independently from others. The pickers are much more mobile and can move from side to side as well as between levels. The only concern is whether the bin filler can sufficiently even out the fruit that is being dumped in heaps on the belts.

Another method of mechanically assisted harvesting that is not widely used is a 225 meter long mobile string conveyor belt that is constructed in the orchard row (Peppelman et al., 2006). Pickers place picked fruit directly onto the conveyor belt, which then transports the fruit down the row to where the automatic bin-filler is stationed. A varying number of workers can pick at the same time. Once the picking is done, the conveyor needs to be taken down and set up in the next row; this only requires two people. The rest of the team can either wait or if there is an alternative harvesting method available, they can continue harvesting. One worker is necessary to operate and manage the changing and logistics of the bins. This method can be used on terrain where tractors have difficulty operating, e.g. orchard floors after heavy rains, steep slopes, etc. (Peppelman et al., 2006).

4.5. Other:

Research is being done with regard to robotic harvesters that completely replace the pickers. This type of robotic harvesting is expensive and early machines had problems with removing all the fruit from the tree. In some cases up to 30% of the crop could not be retained (Sarig, 2005). The majority of these machines are still in prototype phase and not currently viable options for the industry (Baeten et al., 2008; Bulanon and Kataoka, 2010). It, however, seems that these types of machines will require rigidly homogenous orchards and trees to function properly (Calvin and Martin, 2010).

5. Recent developments in the mechanization of the deciduous fruit industry

When conducting research on the productivity and quality of orchard tasks, it is important to consider the context and circumstances under which the trials take place. Factors such as demography, tree size and shape, crop load uniformity, cultural practices, worker and management motivation/incentives, and fruit quality and size differs between countries, production areas and seasons. All of these factors must be taken into account when interpreting results. Therefore, both the relative and absolute differences between platforms and conventional methods should be considered and in many cases this limits the scope of generalizations and comparisons that can be made. Furthermore different industry standards, ways of measurement and units of measurement also complicate the interpretation of results and should be mentioned in order to convey a representative and realistic message. Lastly, trials are often conducted under ideal weather conditions in ideal orchards which does not necessarily provide the industry with realistic figures as to what the potential of different harvesting methods are (Peppelman et al., 2006).

According to Schupp et al. (2011), research on mass removal mechanical harvesters (“tree shakers”) in the 1970s and 1980s preceded work done on the development of laborer platforms and harvesting systems from the 1990s onward. This change of focus for research was due to the excessive fruit damage caused by mass removal mechanical harvesters that led to the majority of the fruit harvested not being suitable for the fresh market (McMechan, 1968; Peterson, 2005b; Sarig, 2005; Shepardson et al., 1970). In addition, mass removal mechanical harvesters require fruit to ripen equally and to be resistant to damage (Baeten et al., 2008), which are two characteristics not commonly found in deciduous fruit. Thus the use of laborer platforms allowed farmers to increase harvesting productivity without compromising fruit quality (Lesser et al., 2008; McMechan, 1968).

Even though harvest assist machinery available at the moment are not the immediate solution to the labor crisis producers are facing, it is pointing further developments in the right direction (McFerson, 2010). The research in industries that experience labor shortages focus their work on productivity, fruit quality, worker comfort and safety as well as the attractiveness of working in orchards in an attempt to retain a workforce for the fruit industry and also enlarge the worker pool by enabling conventionally unsuited/unwilling laborers to perform orchard tasks at greater ease (Elkins et al., 2010; Lesser et al., 2008; Peppelman et al., 2006). In South Africa, research is mainly focusing on improving farming efficiency under rising production costs with the supply of labor not being that much of a concern as of yet and the better working environment being an added benefit.

5.1. Current levels of productivity and how it is measured

From the literature it is evident that the use of platforms and harvesting systems does not necessarily lead to an effortless increase in productivity, nor is the farm level implementation of these machines always a streamlined operation. There are a few cases where productivity is decreased, but the most literature point to platforms and harvesting systems increasing productivity or having no effect on productivity levels compared to conventional methods as will be discussed below.

With conventional harvesting methods, workers are effectively picking only 30% of the time (Calvin and Martin, 2010). This means that 70% of the day is spent walking to and from bins, emptying harvesting bags, climbing up and down ladders and taking breaks. Therefore, there is a drive towards efficiency in fruit production and many farmers are looking toward mechanization and mechanical aids to play a major role here. Mobile platforms have the potential to increase the percentage of time spent picking if implemented correctly (HDC News, 2010; Lesser et al., 2008). In Italy, it is estimated that a single platform should be able to handle 10 ha of fruit throughout the year (Hansen, 2011). In South Tyrol, an annual average of 593 man hours is needed per hectare to produce apples with the use of platforms.

5.1.1. Orchard tasks other than harvesting

Sazo et al. (2010) reports that the use of platforms reduced labor costs by 20-35% when dormant pruning and that the type of platform has no major impact on labor efficiency. A dormant pruning trial in a mature 'Gala' and 'McIntosh' Tall Spindle apple orchard showed an increase in productivity of 37% (Sazo et al., 2010). The authors found that the saving in labor costs for hand thinning and dormant pruning was twice as much as for trellis installation. Comparison of a single level platform and conventional practice in apple and peach orchards in Pennsylvania and

Washington showed increases in productivity for most orchard tasks (Lesser et al., 2008), with string placement and peach harvesting showing the biggest increases in productivity, viz. 67% and 59%, respectively. Orchard tasks such as apple and peach dormant pruning, apple summer pruning, tree training and green fruit thinning gave productivity increases between 19% and 53% (Table 1).

5.1.2. Harvesting

Trials done with the DBR conveyor pneumatic harvesting system resulted in a 10% to 49% increase for harvesting 'Golden Delicious', 'York' and 'Pink Lady' apples (Schupp et al., 2011). McMechan (1968) performed an experiment comparing conventional bin-on-the-ground-harvesting with a single level platform in a commercial apple orchard with a row spacing of 6.4 by 6.4 meters; the orchard was not pruned to accommodate the platform, which led to restricted use of the telescopic work planks. The bottom fruit were picked before the trial started, thus a comparison of ladder work vs. platform work was made. The pickers picked 270 kg of apples per person per hour regardless of the method of harvesting (McMechan, 1968). Even though this trial was done 40 years ago, the researchers experienced much of the same difficulties as other researchers in more recent trials.

Elkins et al. (2010) performed trials with a conveyor type harvesting system in Northern Californian 'Bartlett' pear orchards, which bear much similarity to South African pear orchards. Tree heights ranged from 4.3 to 5.7 m, with planting densities between 640 and 834 trees·ha^{-1} and the canopy width of the vase shaped trees were between 1.4 and 3.4 m. Productivity was determined by measuring the time it took to fill a 500 kg bin. Conventional harvesting resulted in 221-353 kg·hour^{-1}·picker^{-1} with much more variation observed on the platform with outputs ranging between 82-400 kg·hour^{-1}·picker^{-1} (Table 2).

Peterson (2005a) conducted a trial with the simplified conveyor type harvesting system they developed. It was done in a V-trellis 'Golden Delicious' apple orchard with trees planted at 1.2 by 4 m and an average yield of 100 ton·ha^{-1}. Productivity for the harvesting system was determined by recording the average time it took to harvest four bins separately whereas the productivity for the conventional pickers was measured over the course of a day. The four pickers on the machine harvested 534 kg/hour/picker compared to 438 kg·hour^{-1}·picker^{-1} for conventional picking. The time it took to change bins on the harvesting system was not measured, thus the reported productivity levels overestimates the potential of the machine under realistic farming conditions.

In an extensive comparative study on different harvesting methods Peppelman et al. (2006) compared harvest productivity, harvest injuries as well as certain working environment factors for direct harvesting into bins on a bin trailer, bin-on-the-ground-harvesting with a bin trolley and harvesting bags, a collapsible conveyor belt system and a multilevel laborer platform with conveyor type harvesting system. The trials were conducted in a seven-year-old 'Jonagold' apple orchard on the first of two selective picks. Yield was estimated to be 70 ton·ha^{-1} of which 50 ton·ha^{-1} was harvested with the first pick. Trees were planted in single rows at 3000 trees·ha^{-1} and on average exceeded 2 m in height. Productivity was determined by measuring the time required to harvest 100 apples and converting this into kg·hour^{-1}·picker^{-1}. The researchers also recorded the time for all the other activities when pickers were not actively picking such as changing bins, etc. The output without factoring in other activities as well as taking other activities into account were 490 and 361.8 kg·hour^{-1}·picker^{-1}, respectively, for direct harvesting into bin trailers, 426 and 310.9 kg/hour/picker for harvesting with bin trolleys and harvesting bags, 524 and 325.3 kg·hour^{-1}·picker^{-1} for harvesting with a string conveyor and 447 and 326.4 kg·hour^{-1}·picker^{-1} for harvesting with a conveyor type harvesting system.

According to Hansen (2011), the average worker in Italy on a ladder picks 130-150 kg·hour^{-1}. Research conducted under realistic conditions on farms in Italy that use platforms and harvesting systems indicated that the average laborer on a platform or harvesting system picks 183 to 266 kg·hour^{-1} depending on cultivar and the number of picks (K. Martini, personal communication). Conventional harvesting outputs in South Africa average in the range of 120-150 kg·hour^{-1}·picker^{-1} (M. van der Merwe and B. du Toit, personal communication). Evidently a simple comparison is not easy and the way of measurement in trials as well as the trial set-up and conditions can result in unnaturally high outputs that cannot be directly compared to conventional outputs.

5.2. Factors influencing productivity

Pickers work more efficiently from the ground than when working on ladders (McMechan, 1968). Thus when platforms replace ladders, it eliminates climbing inefficiencies, but it can also cause other inefficiencies. Workers are restricted to the workspace on the platform causing them to work together as a team (McMechan, 1968). In a team environment, workers influence each other mentally as well as physically with the slower workers usually holding back the faster workers (Elkins et al., 2010; McMechan, 1968; Peterson, 2005a; Sazo et al., 2010). Individualism is an advantage especially when doing piece rate work; each worker motivates himself and sets his own goals and therefore platforms should allow pickers to move around as the work necessitates it (McMechan, 1968; Peterson, 2005a).

The team aspect emphasizes inefficiencies caused by a misalignment of machine and orchard design. Elkins et al. (2010) found that if trees are too tall for the platform, pickers struggle to reach the top fruit thus holding up the rest of the team and the opposite happens when trees are too short when the pickers at the top have fewer fruit to pick than the bottom pickers (Peppelman et al., 2006). Peppelman et al. (2006) recorded an output of 252.8 kg·hour^{-1}·picker^{-1} for the conveyor type harvesting system in a part of the orchard where the trees were a maximum height of 2.5 meters representing a 20% drop in productivity from the 326.4 kg/hour/picker recorded in a more suitable part of the orchard with taller trees. This is important to note when using platforms in young orchards that have not reached their full height.

Irrespective of the harvesting method, selective picking slowed down the picking rate compared to strip picking (Elkins et al., 2010) and the higher the number of picks for selective picking, the lower the productivity level (K. Martini, personal communication). The researchers do not give a reason for this, but it might be partly explained by the fact that the picker needs extra time to decide which fruit to pick and which ones to leave.

As the number of people on a platform increase, the picking rate decreases irrespective of the type of picking (selective vs. strip). However for conventional harvesting, the output per picker does not change much with the size of the team (Elkins et al., 2010). Elkins et al. (2010) found that five pickers on a platform achieved 300 kg·hour^{-1}·picker^{-1} compared to 179 kg·hour^{-1}·picker^{-1} achieved when eight pickers were picking on the platform. When strip picking, the five pickers on the platform achieved an output of 400 kg/hour/picker compared to the 208 kg·hour^{-1}·picker^{-1} for eight pickers. It is important to note that the five pickers were paid piece rate compared to the eight pickers being paid hourly and that the monetary motivation probably had an influence on the outputs generated. However, both the hourly paid and the piece rate five-picker-teams on the platform picked faster than conventional pickers. The picking rate for the conventional pickers was constant at around 220 kg/hour/picker for selective picking and 345 kg/hour/picker for strip picking, regardless the number of pickers. This suggests that an increasing number of pickers on the platform lead to inefficiencies that bring down overall productivity, which is not the case with conventional harvesting where pickers can quite comfortably operate independently from each other.

As just described, the monetary incentive for pickers influence the level of productivity and if not managed and monitored properly piece rate may have a detrimental effect on harvesting injuries because pickers are trying to work as fast as they can in order to maximize remuneration. This is one of the main reasons farmers in European countries have moved away from incentive based payment (Peppelman et al., 2006). It is interesting to note that hourly paid European workers are not much less productive than piece rate paid South African workers. One should not assume that this is solely due to monetary compensation because European and South African orchards differ in many respects aspects.

(Peppelman et al., 2006) suggest that the longer the distance between the place of picking and the place of deposit, the longer the length of the picking cycle and the lower the picking rate should be (Table 3). Picking cycle length is the time it takes for the picker to pick a fruit and place that particular fruit in the bin, harvesting bag or conveyor. It is interesting to note that the picking cycle lengths do not correlate with the hourly picking rates the researchers obtained. When the cycle lengths are converted into kg/hour/picker, the outputs are much less than what the researchers obtained by converting the time it takes to pick 100 apples into kg/hour/picker, even when assuming two handed picking (halving picking cycle length). Harvesting directly into bin trailers had the longest picking cycle length, but had the second highest hourly output when not taking other activities into account. This suggests that for the other methods there are serious causes of inefficiencies in between picking cycles that add up to a considerable wastage of time and therefore lower productivity or that the method of measuring productivity (time/100 apples) failed to capture the actual situation.

Although production techniques and circumstances are not exactly the same, there is still much to learn from these European countries with regard to the implementation of platforms in order to increase production efficiencies. Europe has smaller trees and therefore sees larger gains in productivity with the use of platforms and harvesting systems. Trees in South Africa are generally bigger and it is more likely to obtain results closer to those Elkins et al. (2010) found.

5.3. Quality of the work done

Once picked, fruit are exposed to numerous potential damaging situations, e.g. placement into bin, transport, bin tipping, sorting, packaging, etc. with bruising the most common form of damage (García et al., 1995). Along this series of events, fruit usually accumulate injuries (García et al., 1995). Larger fruit bruise more easily and more severely than smaller fruit and when there is apple to apple contact, the stationary apple is bruised more severely (Lewis et al., 2007). The materials used on a harvesting system can influence bruising by means of their energy absorbing capacity. Materials such as wood and cardboard that have higher energy absorbing capacities will cause less bruising than materials such as steel and rubber on steel (Lewis et al., 2007).

Researchers in Europe reported that harvesting systems with bin fillers decreased fruit injuries, but in the USA it was found to increase injuries and was the main reason for these machines not being commercially adopted (Robinson and Sazo, 2013). Interpreting and comparing fruit injury results from different trials in different countries is difficult because the different industries have different standards by which they classify damaged fruit. In order to measure the economic impact of alternative harvesting methods one needs to quantify harvesting quality as well as the quality of other orchard tasks compared to conventional methods (Rudkin et al., 1973).

Elkins et al. (2010) found an 8% decrease in stem punctures for pears harvested with a conveyor type harvesting system (6%) compared to conventional picking (14%). Peppelman et al. (2006) found that apples harvested with a string conveyor as well as directly into bin trailers were more severely bruised than apples harvested with a conveyor type harvesting system with 5% compared to 2% bruising. Pneumatic type harvesting systems damaged 'York' apples less than the conventional harvesting with 4% less 'York' apples downgraded because of bruising. Similar levels of damage were found for 'Golden Delicious' and 'Pink Lady' apples (Schupp et al., 2011). It is believed to be the bin fillers that cause most of the injuries resulting in slightly higher bruising than a properly managed conventional team (Robinson and Sazo, 2013). There seems to be a certain amount of damage that is attributable to the machine (≈ 5%) with damages above that caused by human negligence (Robinson and Sazo, 2013). This suggests that the incidence of harvesting injuries when using harvesting systems is cultivar dependent and that there is a certain threshold sensitivity limit above which there is no difference between harvesting system and conventionally harvested fruit.

Peppelman et al. (2006) found that when harvesting directly into bins on bin trailers the pickers sometimes are far away from the bins and consequently carry more than one apple in each hand at one time. This is a concern for some producers because carrying a number of fruit at once increases the chance of fruit injury (C. Groenewald, personal communication) and this is probably the primary reason for the difference in bruising on apples found by Peppelman et al. (2006). Conveyor type harvesting systems do not seem to influence fruit quality for day and night harvested pears or have any impact on post-harvest quality when compared to conventional harvesting methods (Elkins et al., 2010). Streak type damage and puncture wounds on apples are also not affected by harvesting method (Peppelman et al., 2006).

Research suggests that the more aligned the platform design and tree training system, the better the quality of work (Lesser et al., 2008). One of the few examples of quantifying the quality of orchard tasks is found in the paper by Lesser et al. (2008). The authors report that there was an increase in work quality for thinning because the fruit count was lower for platform thinned trees than for ladder thinned trees. Whether this really indicates a higher quality of work is questionable. The fruit counts would have been of more value if the thinning recipe was given or the actual fruit numbers vs. predicted fruit numbers were given. Another way of potentially measuring the quality of orchard tasks is to record the number and severity of faults per tree. This is an indication of how difficult it is to quantify the quality of the work done because there are so many factors to consider.

5.4. Working environment

The implementation of platforms creates new issues with regard to worker safety, but the majority of these should not be a problem if the orchard and the machine are fully compatible (Elkins et al., 2010). In developed countries routine labor inspections are done to ensure a safe working environment for the laborers (Hansen, 2013). These inspections assess how hazardous and physically demanding the work is and whether it exceeds certain exertion and body posture limits (Hansen, 2013; Peppelman et al., 2006). This necessitates research to focus on worker safety and comfort whereas in less developed countries it receives much less attention with loose legislation around worker safety.

In contrast to the work of other researchers Peppelman et al. (2006) used quantitative methods to compare the working environments of the different harvesting methods. The exact methodology is presented in Peppelman et al. (2006). Although picking and other orchard tasks are repetitive and mundane, the seasonal nature of these tasks cause fewer injuries and health problems than would have occurred should these tasks be performed for longer periods of time (Peppelman et al., 2006). Multilevel platforms with harvesting systems result in the most favorable head and upper arm angle and position when harvesting because each picker stands at a different height with the picking being done from waist to eye level. From the researchers' point of view one concern with regard to the harvesting system was that the people picking from the ground are constantly bending down to reach the lower apples, which may cause excessive stressing of the back and it is therefore advised to rotate the workers on the machine on a regular basis (Peppelman et al., 2006). Once workers have experience of working on a platform, they seem to enjoy the less strenuous and safer working environment and they prefer working on a platform rather than bin trailers, string conveyors and bin trolleys with harvesting bags (Elkins et al., 2010; Peppelman et al., 2006).

6. An analysis of deciduous fruit farming practices with regard to mechanization

The process of mechanizing deciduous fruit farming may require changes at farm level in terms of the cultivars planted, cultural practices, tree training, orchard design, labor dynamics and incentives, operational systems and harvest logistics (Calvin and Martin, 2010). In the long run, mechanization can alter the structure of an entire industry with regard to the number of producers and size of units in the industry, depending on where there are efficiencies to be gained (Lesser et al., 2008). The overall trend in agriculture is toward fewer but larger production units (Calvin and Martin, 2010).

Over the years, harvesting with all of the processes involved in it have been adapted and streamlined in order to make for a more efficient operation. This has led to interdependency between operational setups, equipment and labor. Consequently, it is difficult for machinery to take the place of a human picker seeing that it will need to fulfil a very specific task whilst allowing the rest of the process to continue undeterred. The ideal machine will need to induce high productivity, good quality work, allow for in orchard sorting, flexibility in terms of management and compatibility, low cost, robustness, simplicity, ease of repair and a safe and comfortable environment for workers (Elkins et al., 2010; McMechan, 1968; Schupp et al., 2011). There seems to be a trade-off between the capabilities of the machine and cost, i.e., simpler machines are cheaper, but they seem to lack in adjustability, worker safety and comfort. For this reason it is unlikely that a single machine will be able to fulfil all the needs of a specific producer.

Conventional harvesting methods allow the producer to be much more flexible in the way the workforce is managed in order to deal with peak harvesting periods. Each laborer works with his own ladder and bag and the size of teams can therefore be adapted without having a great impact on performance (Elkins et al., 2010) whereas with a platform, the producer is limited to the number of people that can work on a platform where the workers are forced to work together as a team and in most cases this negates productivity.

In Italy, platforms are commonly used to pick only the upper canopy while the lower canopy is picked beforehand using conventional methods such as a bin trolley or bin trailer (K. Martini, personal communication). On larger production units, this type of operational setup will require an immense organizational effort because there will be double movement through the orchards. Another concern is that the lower and upper canopy fruit differ in quality. Pack houses often make use of this to increase the percentage of exportable crop by placing borderline fruit in the same box as top quality fruit (E. Heydenrych, personal communication). Consequently, if top and bottom fruit are to be harvested separately, pack houses will no longer have that option.

Apart from bin trailers, all other commercially used harvesting methods leaves the farmer with full bins in the orchard row that somehow must be transported to a loading bay from where it is taken to the pack house (Peppelman et al., 2006). This puts farms that employ a conventional bin-on-the-ground-harvesting setup in a much better position to adopt laborer platforms and harvesting systems should the need arise. Such farms already have the equipment and operational setup required to move the bins out of the rows to the loading bays. Thus a transition to mechanical harvesting will be much easier to facilitate. Farms that are currently harvesting with bin trailers are much less suited for such a transition. These farms do not necessarily have the equipment required to move bins out of the rows to the loading bays and the equipment such as the bin trailers are in some cases rendered useless. Furthermore, it is going to be much more of a challenge for these farms to get operational procedures in place that will accommodate mechanical harvesting as well as to get the workforce accustomed to the new operational setup.

Harvesting systems usually have trailers that can hold a number of empty bins. This simplifies the logistical procedure of supplying the pickers with empty bins (Peppelman et al., 2006). The forklift operator can load empty bins whenever there is time and focus more on getting the full bins out of the orchard as quickly as possible. With other harvesting methods the person tasked with supplying the pickers with empty bins is under pressure to keep the whole harvesting process running as smoothly as possible. This takes organizational effort and can lead to the pickers being inefficient while waiting for empty bins (Peppelman et al., 2006).

7. Concepts in existing models for the economic analysis of agricultural machinery

The majority of mathematical machinery selection models available were developed for field crops such as the models developed by Camarena et al. (2004), Lazzari and Mazzetto (1996) and Aderoba (1987). Though not directly applicable, the concepts and ideas used in these models give insight as to what factors to consider when developing machinery selection models for the deciduous fruit industry.

Aderoba (1987) developed a model for selective mechanization of field crops for small farmers that allows producers to decide on the most affordable way of partially mechanizing their setup. The researcher opted for a selective mechanization approach because of the difficulties small farmers experience with regard to full scale mechanization. A selective mechanization approach toward fruit production makes sense because the technology currently available for full scale mechanization is expensive, not yet proven and not necessarily interchangeable between different countries and production systems (Sarig, 2005). Therefore a selective mechanization component in a model will allow producers to see what effect the mechanization of only certain orchard tasks may have.

Alternatively, Camarena et al. (2004) suggests that smaller farmers consider a joint ownership approach when buying expensive mechanization machinery. This approach is commonly seen in European fruit producing regions where production units are relatively small (3 to 17 ha) (K. Martini, personal communication) and individual farmers will not be able to justify the capital investment on their own. Joint ownership of mechanization machinery is a less viable option in countries with larger production units such as South Africa. The same concept could, however, be applied to large corporations with multiple production units in various production areas that could benefit from economies of scale when investing in expensive mechanization machinery.

Rudkin et al. (1973) focused on capturing the variable nature of fruit production in a decision model for apple harvester selection. The model recognizes the natural yield variability between trees in an orchard, varying harvesting system productivity as well as costs related to system's productivity and economic life (Rudkin et al., 1973). The researchers assumed the density of fruit in an orchard to be the major source of variation in harvesting system productivity and used apple yield data to include this variability in the model formulation by determining average yield together with the variance needed to simulate actual conditions. Other uncontrollable sources of variable system productivity are adverse weather conditions and variation in terrain (Rudkin et al., 1973).

At this point it is important to note that measures of system productivity and economic efficiency differ in the sense that the former is measured in units of output per unit of time and the latter is measured in terms of monetary value of output per monetary unit of input (Rudkin et al., 1973). The importance of the difference between these measures lies in the fact that the most productive harvesting system would not necessarily be the most economically efficient (Rudkin et al., 1973). At the same time it does not mean that the economically most efficient harvesting system is the one producers should and would choose because producers consider other non-economic and principle based factors as well (Lazzari and Mazzetto, 1996).

Producers want models to be very adaptable in order to be used for specific situations on specific farms. Therefore models should be user friendly and allow changes in any variable to allow sensitivity analysis with regard to critical parameters (Camarena et al., 2004; Lazzari and Mazzetto, 1996).

8. Training new orchards to accommodate future mechanization without compromising profitability and fruit quality

Sunlight strikes the earth's surface at a larger angle (closer to perpendicular) in countries situated at lower latitudes than countries at higher latitudes. This enables deciduous fruit growers in South Africa to grow taller trees without incurring problems with shading whereas it forces producers in Europe and the United States of America to grow shorter trees (Perry et al., 2008).

Shorter trees, as found in European countries, reduce the ladder work needed and increase productivity (McMechan, 1968). For this reason some producers are considering to get rid of platforms and ladders to create orchards where trees are fully accessible from the ground (Hansen, 2011). In contrast, Peppelman et al. (2006) advises European growers to grow taller trees because pedestrian like orchards cause inefficiencies when harvesting with a multilevel harvesting system. Bigger trees such as found in South African fruit orchards translate into higher yields and it is not uncommon to find commercial apple orchards in South Africa yielding in excess of 100 ton/ha. Therefore the option to grow smaller trees in order to gain productivity is not that viable because it might lead to a decrease in yield (McMechan, 1968).

Training orchards to allow full scale mechanization in the future would benefit current conventional practices as well as harvesting aids (Hansen, 2011). Platforms limit the picker's reach into trees to the length of his arm (McMechan, 1968), thus trees with narrower canopies, such as fruiting walls and tall spindle trees, will allow pickers easy access to fruit when picking from platforms and also ladders (Sazo et al., 2010). Thus training trees with narrower canopies could potentially increase labor productivity irrespective of mechanization (HDC News, 2010).

Trees trained to a single plane will allow producers to standardize certain orchard tasks to a great extent. This is beneficial because the simpler a task, the faster it can be performed and the easier it is to monitor (Lehnert, 2013). It will enable unskilled and inexperienced workers to perform intricate orchard tasks that usually required scarce, skilled laborers (HDC News, 2010). With regard to potential full scale mechanization for tasks such as pruning and thinning, fruiting walls are also considered to be the most suitable. Thorough orchard design and precise tree planting is critical for mechanization and growers in New York have begun to use GPS technology when planting in order to ensure evenly spaced rows (Sazo and Robinson, 2013; Sazo et al., 2010). The precision required together with a more complicated trellis system could lead to an increase in establishment costs (HDC News, 2010).

Growers in NY State are establishing new orchards according to the Tall Spindle planting systems that give higher yields than traditional systems and are easier to maintain. In addition, the narrow and adaptable canopy of the Tall Spindle system can accommodate laborer platforms, allowing certain orchard tasks to be mechanically assisted (Sazo and Robinson, 2013). It also has the advantage of being simpler and cheaper to train and establish than a fruiting wall system. Hedge cutters can be used on tall spindle trees in the summer to form a fruiting wall type tree that only needs detailed dormant pruning to be done every three years. The vigorous rootstocks that are still in use in South African deciduous fruit orchards might cause regrowth issues when mechanically pruning trees with a hedge cutter. In the end the decision as to what route to take in the future remains in the hands of the producer and each one has to react in a way he sees fit for his farm under the prevailing market and production circumstances.

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Table 1: Percentage increase in productivity obtained with the use of a single level platform compared to conventional practice in commercial fruit orchards in Pennsylvania and Washington (Lesser et al., 2008)

	Pennsylvania	Washington
Green fruit peach thinning	36%	
Green fruit apple thinning	50%	19%
Tree training	49%	48%
Peach harvest	59%	
Apple dormant pruning	53%	27%
Peach dormant pruning	34%	
Apple summer pruning		32%
String placement		67%

Table 2: Harvest productivity results from Elkins et al. (2010).

				Kg·hour^{-1} and number of pickers			
Treatment	Type	Pay	Replicates	5	6	7	8
Platform 1	Selective	Hourly	10		172	148	82
Platform 2	Selective	Hourly	1	300			179
Platform 3	Selective	Hourly	2				129
Average	Selective			300	172	148	117
Conventional	Selective	Piece		222	217	226	221
Platform 1	Strip	Hourly	4				188
Platform 2	Strip	Hourly	6				208
Platform 2	Strip	Piece	1	400			
Platform 4	Strip	Hourly	1				250
Average	Strip			400			208
Conventional	Strip	Piece		353			341

Table 3: Harvest productivity results from Peppelman et al. (2006).

Method	Picking (Kg·hour^{-1}·picker^{-1})	Overall (Kg·hour^{-1}·picker^{-1})	Picking cycle length	Fruit·hour^{-1}	Kg·hour^{-1}	Apples in hand
Bin trailers	490	361.8	9.6	375	75	3.08
Bin trolley and Harvesting bag	426	310.9	5	720	144	2.03
String conveyor	524	325.3	6.1	590	118	2.52
Pluk-o-trak	447	326.4	7	514	103	2.46

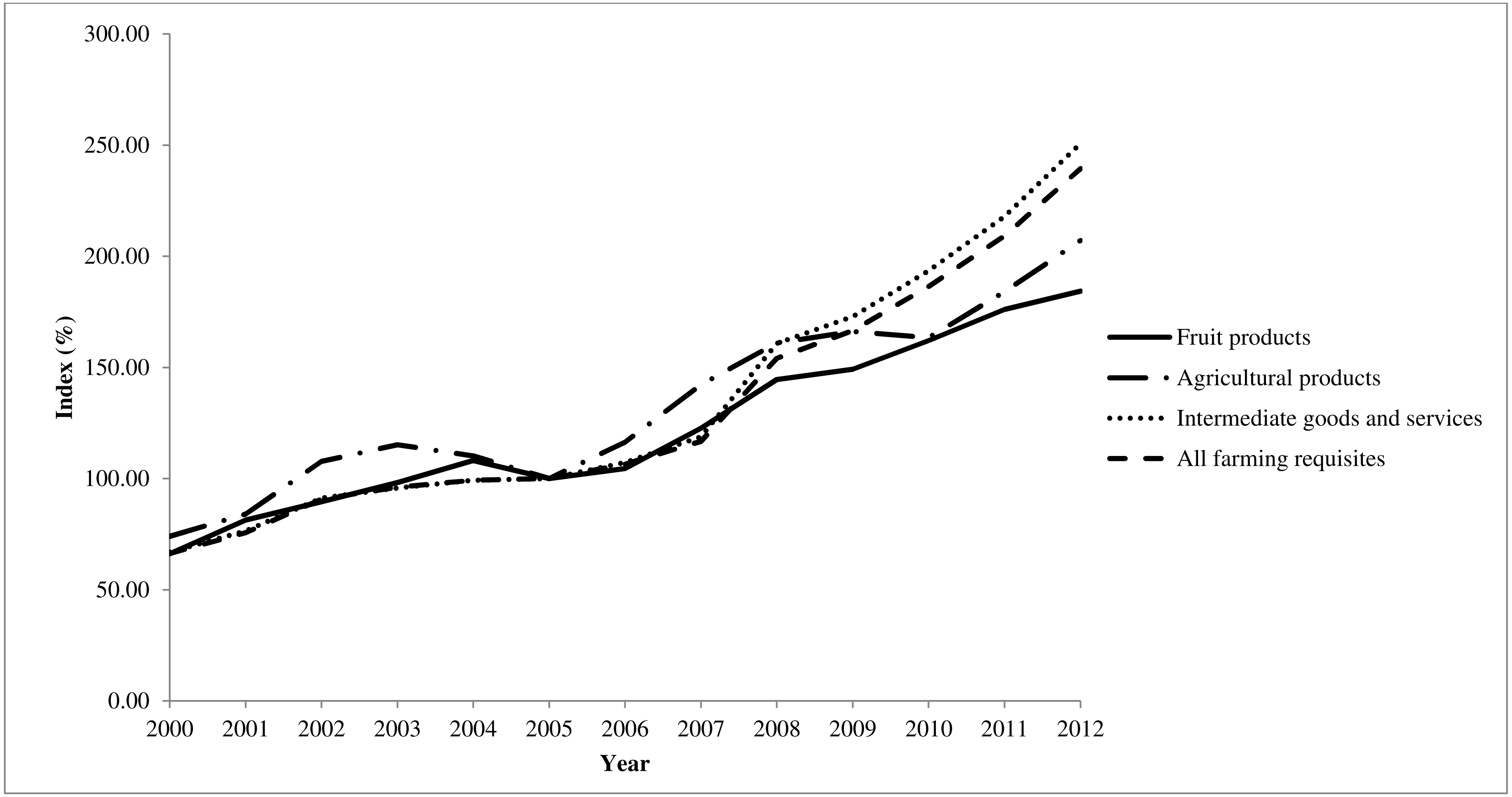

Figure 1: Various price indices for the time period 2000 - 2011 (2005=10) (Source: Self constructed from Directorate Statistics and Economic Analysis (2013)).

PAPER 1: THE USE OF HARVESTING SYSTEMS AND LABORER PLATFORMS FOR HARVESTING IN THE SOUTH AFRICAN DECIDUOUS FRUIT INDUSTRY

Additional index words. Harvest productivity, mechanization, conventional practice, picking efficiency, orchard adaptation

Abstract

Harvesting is the most labor intensive action performed on a deciduous fruit farm and creates a seasonal demand in casual labor. Harvesting systems and laborer platforms were compared to conventional harvesting in various production areas on pome and stone fruit to evaluate the effect of these machines on laborer productivity during harvesting. The aim was to evaluate the machines under standard commercial working conditions on farms and therefore full day replicates were used as far as possible. Picker productivity was measured in terms of the mass of fruit harvested within a certain period of time. In two trials overall picking efficiency was determined for conventional harvesting compared to harvesting systems and platforms. The lack of uniformity in South African deciduous fruit orchards and the misalignment between orchard and harvesting system design resulted in an inefficient picking action for the laborers on the harvesting systems. This caused an overall decrease in laborer productivity during harvesting. Decreases in productivity were largest on less injury prone apple cultivars such as Red Chief and Cripps' Red. Conventional teams tended to achieve high productivity outputs of 200 – 260 kg·hour^{-1} on these cultivars whereas the productivity outputs for the harvesting systems seemed to be limited to ≈150 kg·hour^{-1}. With conventional picking, 59 – 65% of the day is spent emptying bags and climbing ladders whereas with harvesting systems only 43 – 44% of the day is spent not picking. However, the misalignment between orchard and machine design limited the potential picking rate a picker could achieve and in doing so caused an overall decrease in harvesting productivity. Few South African orchards and operational systems are suitable for the implementation of these machines and much optimization and investment will be needed to mechanize the harvesting process. Furthermore, the adaptation of existing orchards to accommodate harvesting systems and platforms can decrease yield. Factors such as tree size, shape and uniformity, fruit distribution on the tree, fruit size and quality, orchard floor condition and aspect, labor team dynamics, harvesting incentives, bin condition, operational

system employed and harvest logistics all affected the feasibility and ease of harvest mechanization.

Introduction

Mechanization in South African agriculture shows the same trends as in many developed countries, but the driving forces behind these trends differ between these countries and South Africa (Simbi and Aliber, 2000). Non-economic factors such as the uncertainty created by land reform policies, social problems, conflicted labor relations and difficulties experienced with organizing a large labor force have been major driving forces behind agricultural mechanization in South Africa as discussed by Schirmer (2004) and Simbi and Aliber (2000). Although the fears and problems might still be the same today for deciduous fruit farmers, it is unlikely that large scale non-economic driven mechanization will be possible in the industry. The government policy and regulations that made such mechanization possible in the past, does not exist anymore and producers are forced to take into account the economic forces acting for and against mechanization in the deciduous fruit industry.

Harvesting is the most labor intensive action on a deciduous fruit farm, but the manpower needed for harvesting a hectare of apples varies, ranging from 120 man-hours/ha in the USA (Peterson and Miller, 1989) to 300 man-hours/ha in Europe (Peppelman et al., 2006). This labor intensiveness of deciduous fruit harvesting creates a very seasonal demand for labor (Schupp et al., 2011). If platforms and harvesting systems can decrease the amount of labor needed at harvest time, producers can employ the same laborers year round, which will give stability and security to both producer and laborer (McMechan, 1968). At the moment, conventional harvesting methods allow producers to rapidly adapt the size of workforce during harvesting peaks without disrupting productivity (Elkins et al., 2010). This might not be the case when a farm is fully dependent on harvesting systems and platforms to harvest the crop.

Researchers in the United States and Europe have been evaluating the use of platforms as harvest aids since the early 1960's, but little progress has been made in implementing the technology on farms. Current research still come to the same conclusions, i.e., that higher planting densities and trees with narrow canopies are needed in order to increase the productivity of workers on platforms (Elkins et al., 2010; Fridley, 1977; McMechan, 1968). Researchers in the USA have worked on fully mechanized fruit harvesters in an attempt to lessen the labor needed at harvest time, but none of these machines were commercially adopted by farmers producing for the fresh fruit markets (Sarig, 2005). These harvesters caused excessive damage to fruit and some of them were not very efficient in removing all the fruit from the trees (Peterson et al., 1994; Sarig, 2005). During the 1990's research focus shifted from mass removal harvesters back to the development of laborer platforms (Schupp et al., 2011). Twenty years later orchards are planted at higher densities, but large, consistent increases in harvesting productivity with harvesting systems and platforms are still not attained (Elkins et al., 2010; Robinson and Sazo, 2013; Sarig, 2005).

The modern day conveyor type harvesting systems and platforms were developed and built predominantly in Europe. These machines are being used in European countries (Sarig, 2005) and many South African producers have visited farms where these machines are being successfully implemented with the aim to do so in South Africa as well. According to Peterson (2005), conveyor type harvesting systems never increased labor productivity to the extent where producers in the USA widely implemented them. Non-uniform fruit distribution, picker positioning and the effect the slowest picker had on the rest of the team all led to idle time for some pickers and therefore a loss in productivity (Peterson, 2005). American researchers developed a pneumatic type harvesting system that transports picked fruit inside a padded tube rather than on conveyors. Increases in productivity seen with these machines vary and further testing is required to validate the commercial feasibility of such harvesting systems (Schupp et al., 2011). According to Fridley (1977), the use of laborer platforms increased harvesting productivity by 20% for inexperienced pickers but it does not necessarily increase the productivity of well-organized experienced pickers. These inconsistent results concur with the findings of Cuskaden (1973) that there are many factors that influence the productivity of the individual picker, not just the harvesting method.

The research by Elkins et al. (2010), McMechan (1968) and Peppelman et al. (2006) found that there are other non-economic advantages stemming from the use of these machines. Peppelman et al. (2006) found that picking on harvesting systems were less strenuous than with harvesting bags. This is important to note in terms of long term worker safety and injury, especially if legislation becomes stricter as it has in European countries (Peppelman et al., 2006). It also allows people previously excluded from the labor pool to pick during harvest time while at the same time bring stability to the labor pool (Elkins et al., 2010; Schupp et al., 2011). It is important that the machinery employed aid the workforce in what they are doing, not restrict their capabilities as was seen in cases where the misalignment between machine and orchard design led to workers not being able to reach fruit or not having enough space to work in (McMechan, 1968). An effort was made in this study to quantify the limiting effect of harvesting systems and platforms when they are used in unsuitable orchards.

Sarig (2005) warns against indiscriminately using mechanized alternatives without considering the unique challenges of each situation and circumstances because it can lead to economic losses that may force producers out of business. Therefore HORTGRO science acquired a Hermes Tecno L™ conveyor type harvesting system in order to test it under South African conditions. Privately owned machines were also included as producers started buying them. Many South African orchards are not suitable for the use of harvesting systems or laborer platforms, thus the option to adapt existing orchards to allow access for these machines was explored.

Materials and Methods

Production areas

Fourteen trials were performed during the 2012/13 and 2013/14 harvesting seasons on farms in various deciduous fruit production regions in the Western Cape, South Africa. Trials 1 to 3 and 6 were carried out on Kromfontein in the Koue Bokkeveld (32°57' S, 19°14' E), trials 4 and 7 to 9 on Paardekloof in the Witzenberg Valley (33°15' S, 19°15' E), trials 5, 10 and 11 on Oak Valley Estate in Grabouw (34°9' S, 19°2' E), trial 12 on Heldersig in the Koue Bokkeveld (32°50' S, 19°16' E), trial 13 on Aanhouwen in Grabouw (34°12' S, 19°2' E) and trial 14 on Uitvlug in Tulbagh (33°15' S, 19°8' E). Orchard and trial information are provided in Tables 1 to 3.

Experimental design

Harvesting systems and platforms were assessed under standard commercial working conditions. Full day replicates were used as far as possible in order to capture the realistic potential of the harvesting systems by including standard inefficiencies of the specific orchard/farm that might be excluded when using rows as replicates, e.g. the time it takes to move between rows, emptying cull fruit bins/containers, bathroom breaks, etc. A formal trial layout would have disrupted the conventional harvesting process because the harvesting systems and platforms harvested the trees only on one side requiring another pass in the adjacent row to harvest the remaining side. In contrast, the conventional teams harvested both sides of the tree row in one pass. For this reason and as well as to prevent unnatural competition between workers, the harvesting systems and platforms were evaluated in separate sections of orchards. The trials where and the reasons why days as replicates were not used will be discussed for these trials individually. Laborer experience was documented in an informal manner as to keep answers honest and sincere. Laborers were asked to make comments on team dynamics, advantages and disadvantages of the harvesting system as the trials were conducted

In trials 1 to 12 the Hermes Tecno L harvesting system (Hermes, Gargazonne, Italy) was compared to conventional harvesting. In trials 8 and 9 the Zucal Z11™ harvesting system (Meccanica Zucal, Romeno, Italy) was included in the comparison. In trial 13 and 14 the N.Blosi™ (N.Blosi, Ravenna Italy) laborer platform was compared to conventional harvesting. Platform dimensions are shown in Table 4.

Treatment descriptions

Conventional practice

Conventional harvesting for all trials except trials 5, 10 and 11 was done with the tractors-and-bin-trailers-harvesting method (Figure 1). The size of the picking team varied between farms as will be discussed for each individual trial. Picking teams were made up of experienced male pickers, experienced female sorters, two tractor drivers who also picked when they were in the orchard and one foreman/crew boss. For the Kromfontein and Paardekloof trials (Trials 1 to 4 and 6 to 9), pickers worked together in pairs to harvest a row of trees, one picker on each side of the row. For trial 12 on Heldersig, pickers were divided into four groups with each group harvesting a row of trees. For trials 13 and 14 on Aanhouwen and Uitvlug, respectively, pickers were divided into two groups with each group harvesting a row of trees. Each picker was equipped with a ladder and harvesting bag except for trial 13 and 14 where pickers were separated into ground pickers and ladder pickers with only the latter being commissioned a ladder each. When emptying full harvesting bags, pickers had to walk to the tractor-trailer combination, parked in between the two middle rows of all the rows simultaneously harvested. The tractor with trailers intermittently moved forward as the pickers progressed down the rows in order to keep walking distance to a minimum. The sorters continuously removed cull fruit from the orchard grade bin. The culled fruit were placed into a bag which was emptied into a cull fruit bin on one of the trailers. Each picking team had two tractors with three trailers each; a three-bin trailer followed by two two-bin trailers. When the pickers filled all the bins on one tractor-trailer combination, it was driven to the loading area where full bins were replaced with empty bins that then returned to the pickers. Whilst one tractor was at the loading area, pickers emptied their bags into the bins on the other trailers and the process repeated itself. Throughout the orchard there were openings in the rows spaced 20-30 meters apart, allowing the pickers to walk across the rows to get to the bin trailers. The orchard used in trial 8 had no openings and the tractors were parked at the end of the rows as shown in Figure 2. Pickers had to walk down the row to empty their bags. The rows were harvested only halfway from one end of the orchard with the remaining half harvested from the opposite end.

Conventional harvesting for trials 5, 10 and 11 was done with the bin-on-the-ground method (Figure 3). Picking teams were made up of 12 experienced male pickers, six experienced female sorters, one tractor driver and one foreman/crew boss. For each team there was one tractor with a rear-mounted forklift (far-lift) that transported the bins out of the orchard to the nearest loading area. The same tractor was responsible for supplying the pickers with empty bins placed ahead of them in the row. Pickers worked together in groups of four to harvest two rows at a time with one picker on each side of a tree row. The four pickers working together emptied their bags into a bin placed between the two rows they were harvesting. Two sorters per four man team removed all the cull fruit from the orchard grade bin and put it into a separate bin placed in the adjacent row. The tractor with the forklift moved the bins of each four-man team down the row as they progressed, minimizing the distance to be walked.

Harvesting systems and platform

Conveyor belt type harvesting systems mounted on self-propelled multilevel platforms were used in trials 1 to 12. The number of pickers on the harvesting system varied according to orchard and crop conditions, which will be discussed for each trial. In most of the trials, six pickers worked on the harvesting system, i.e., two pickers on the ground in front of the machine, one picker on each side of the machine at mid-level on separate platforms and one picker on each side of the system at the rear of the machine also on separate platforms. All four platforms could hydraulically adjust sideways allowing the picker to get closer to the tree. The two lower platforms could manually adjust vertically with the two higher platforms at the back able to hydraulically adjust vertically allowing pickers to pick at a comfortable height. Each one of the four platforms had an adjustable conveyor belt arm with another two belts extending in front of the machine for the workers picking from the ground. Pickers placed picked fruit onto the conveyor belts, which then deposited it onto a large central conveyor belt that took the fruit to the mechanical bin filler that automatically filled the bins. Bins stood on a rotating platform with the bin filler lowered into the bin. As the bin filled, a sensor automatically lifted the bin filler until an alarm went off signaling that the bin was full. Full bins were discharged either directly onto the ground with the Zucal Z11 or via the bin trailer towed behind the Hermes Tecno L. An off-road forklift (for trials 4 and 7 to 9) and a tractor with a rear mounted forklift (for trials 1 to 3, 5 and 6 and 10 to 12) were used to take the bins out of the row. The operator loaded empty bins from the bin trailer onto the rotating table. For trials 4 and 7 to 9, sorting was done by the pickers whereas in trials 1 to 3, 5 and 10 to 12 it was done by an extra worker standing next to the central conveyor belt. On the Hermes Tecno L, cull fruit was put into a separate container that is fixed on the harvesting system and on the Zucal Z11 it was put into a bin loaded on a fork at the front of the machine.

When harvesting with the platform for trials 13 and 14, pickers stood on the single level platform to pick the top part of the trees. The sides of the platform could be adjusted hydraulically in a sideways manner allowing pickers to get closer to the tree while the height of the platform was hydraulically adjusted by the operator. Pickers placed picked fruit into harvesting bags, which were then emptied into bins on the platform. Pickers picking at ground level emptied their bags into the bin on the front end lift of the platform. Sorting took place on the machine with cull fruit being placed into lugs that were later emptied into separate bulk bins. Full bins were discharged directly onto the ground behind the platform at the end of rows or in the row with empty bins being picked up at the front of the platform by the front end lift for trial 13. For trial 14 full bins were off-loaded onto a trailer fitted with rollers on top and empty bins were loaded by hand.

Orchard sanitation

Fruit that naturally fell off the tree as well as the fruit dropped during the harvesting process were picked up by separate pick-up teams for trials 1 to 4, 6 to 9 and 12 to 14 both for conventional and harvesting system harvesting. Thus the output per picker per day excluded the dropped fruit. For trials

5, 10 and 11 the sorters picked the fruit up as they progressed down the row and put the fruit in the same bin as the cull fruit, both for conventional and platform harvesting. Thus the output per picker per day included the dropped fruit.

Productivity measurements and calculations

For trials where rows were used as replicates, productivity was measured by recording the time needed to harvest a row together with the number of bins harvested in that row. Harvested bins consisted of orchard grade bins as well as the cull fruit bins containing the cull fruit that the sorters removed from the orchard grade fruit. This was converted into bins per picker per 9.5 hour manday (MD) and to kilogram of fruit picked per picker per hour ($kg{\cdot}hour^{-1}$).

For trials where days were used as replicates, productivity was measured by converting the number of bins picked per picker on that day to the number of bins picked per picker in a 9.5 hour MD as well as to the kilogram of fruit picked per picker per hour.

Trial-specific materials and methods

Trial 1: This trial compared conventional harvesting to harvesting with the Hermes Tecno L harvesting system in a 22-year-old ‘Flavour Top’ nectarine orchard. Nectarines were selectively picked as the fruit ripened. Farm management determined the days of harvesting and what fruit were to be removed according to size and fruit color. Selective picking on nectarines necessitates the whole orchard be picked every day of harvesting. Therefore rows were used as replicates in this trial. Harvesting took place on 21 January 2013 as the second selective pick in the orchard. Eight experienced male pickers, an experienced female sorter and an operator who was also the crew boss worked on the harvesting system. There was one picker stationed at each of the six smaller conveyor belts with the other two pickers helping out where they were needed. None of the workers had previous experience working on the harvesting system. Conventional harvesting consisted of a picking team of 16 experienced male pickers, six experienced female sorters, two tractor drivers who doubled up as pickers and a crew boss. The tractors-and-bin-trailers-harvesting method was used (Figure 1).

Trials 2 and 3: These trials were conducted in a 17-year-old ‘Fantasia’ nectarine orchard. Rows were used as replicates. Harvesting for trial 2 took place on 23 January 2013 and for trial 3 on 28 January

2013 as the first and second selective picks in the orchard, respectively. The team from trial 1 worked on the harvesting system and the conventional harvesting was done the same as for trial 1 (Figure 1).

Trial 4: The trial was conducted in a 16-year-old ‘Abate Fetel’ pear orchard. The orchard was adapted during winter dormant pruning in 2012 by heading back branches extending too far into the row in order to allow easier access for the harvesting system at harvest time. Fruit with a diameter of more than 63 mm were picked during the first pick, leaving smaller fruit on the tree to further gain size. Harvesting took place on 18, 19 and 20 February 2013. Six conventionally experienced male pickers and an operator worked on the platform. Four of these men and the driver have worked on the harvesting system in the previous season. The pickers did the sorting themselves. Conventional harvesting was done the same as for trial 1 (Figure 1).

Trial 5: The trial was conducted in a 13 year old ‘Abate Fetel’ pear orchard. The orchard was strip picked after it had already been selectively picked the week before to remove all fruit with a diameter larger than 57 mm. Harvesting took place on 5 to 8 February 2013. Six experienced male pickers, an inexperienced male sorter and an operator who was also the crew boss worked on the harvesting system. There was one picker stationed at each of the six small conveyor belts. None of the team members had previous experience of working on the harvesting system. Conventional harvesting consisted of a picking team of 12 experienced male pickers, 6 experienced female sorters and a crew boss. The bin-on-the-ground-harvesting method was used (Figure 3).

Trial 6: The trial was conducted in a 7-year-old ‘Panorama Golden Delicious’ apple orchard. The whole orchard had to be harvested within two days, thus rows were used as replicates. The fruit were strip picked, i.e., all the fruit were harvested from the tree during a single pick. Harvesting took place on 23 and 24 January 2013. The same team from trial 1 worked on the harvesting system with an additional picker helping on the ground level because the orchard was still young and most of the crop was carried in the lower canopy. Conventional harvesting was done the same as for trial 1 (Figure 1).

Trial 7: The trial was conducted in a 17-year-old ‘Golden Delicious’ orchard. A part of the orchard was adapted for the use of the harvesting system. During dormant pruning during winter 2012, branches extending too far into the row were headed back to within arm’s length from the trunk. The yield from the adapted part was compared to the non-adapted part of the orchard. The orchard was strip picked and harvesting took place on 5 to 7, 9, 11 and 12 March 2013. The team from trial 6 worked on the harvesting system and the conventional harvesting was done by seven different teams that operated as described for trial 1 (Figure 1).

Trial 8: The trial was conducted in a four-year-old 'Golden Delicious Reinders' apple orchard. The orchard was strip picked and harvesting took place on 11 to 16, 18 to 22 and 25 March 2013. Two harvesting systems were used to perform two treatments each. On the Hermes Tecno L, seven inexperienced females harvested in the part of the orchard where trees were taller (3.0 – 3.5 m) and with a heavy crop load in the lower canopy. Three women picked from the ground and the mid-level platforms were adjusted to their lowest level in order to concentrate most of the picking at the bottom of the tree. For the other treatment, six inexperienced females harvested in the part of the orchard where trees were shorter (2.5 – 3.0 m). Four women picked from the ground with two of them occasionally working from the mid-level platforms if needed. The other two women on the upper platforms had to harvest the top parts of the tree. In both treatments there was a dedicated operator who was the crew boss and the sorting was done by the pickers. On the Zucal Z11, seven experienced males harvested in a part of the orchard where trees were taller (3.0 – 3.5 m). Two of these men worked on the harvesting system in trials 6 and 7 as well as the operator who also had to pick while operating the machine. In the part of the orchard where the trees were shorter (2.5 – 3.5 m) with a lighter crop load, only five men worked on the harvesting system. Three men picked from the ground with two men on the harvesting system picking the top parts of the trees. Conventional harvesting was done by three picking teams as described for trial 1.

On three of the days, the number of fruit each picker picked per minute was recorded for the six-picker female team on the Hermes, the 5-picker male team on the Zucal, conventional team 1 and conventional team 2. One observation per picker was made each day to calculate a team average, which is from here on referred to as the 'potential picking rate'. The actual output of bins/MD, from here on referred to as the actual picking rate, was converted into a constant rate of apples picked per minute, i.e., the number of apples that needed to be picked per minute in order to fill a certain number of bins in a given time as if the picker was constantly picking and never had to walk or climb a ladder. The actual rate was taken as percentage of the potential rate, which gives an indication of how much time was spent picking. The percentage inefficiency was calculated from this by subtracting the percentage time spent picking from 100%.

Trial 9: The trial was conducted in a 23-year-old 'Red Chief' apple orchard. The orchard was strip picked and harvesting took place on 25 to 27 March as well as 2 and 3 April 2013. The same teams that did the second treatments in trial 8 worked on the harvesting systems. Conventional harvesting was done by three picking teams as described in trial 1.

Trial 10: The trial was conducted in a 14-year-old 'Cripps' Pink' apple orchard. Harvesting took place from 24 to 26 April 2013 as the first selective pick in the orchard, removing all fruit with at least 50% red color as instructed by farm management. The team from trial 5 worked on the harvesting system, with one of the pickers replaced by the sorter as well as a new experienced female sorter and a new operator/crew boss. Conventional harvesting was done as described under trial 5.

Trial 11: The trial was conducted in a 14-year-old 'Cripps' Red' apple orchard. The orchard was strip picked and harvesting took place on 8, 10 and 14 May 2013. The team from trial 5 worked on the harvesting system. Conventional harvesting was done as described under trial 5.

Trial 12: The trial was conducted in an 8-year-old 'Angelino' Japanese plum orchard. The orchard was strip picked and harvesting took place on 25 February 2013. Rows were used as replicates. There were six male pickers experienced in conventional picking on the harvesting system and two experienced female sorters. There was one picker stationed at each of the six small conveyor belts. None of the team members had previous experience of working on the harvesting system. Conventional harvesting was done via the tractors-and bin-trailers-harvesting method (Figure 1). The conventional picking team consisted of twelve experienced male pickers on ladders and four experienced female sorters, a tractor driver and a crew boss.

Trial 13: The trial was conducted in a full bearing 'Laetitia' Japanese plum orchard. Harvesting took place on 31 January 2013 and 1 February 2013 as the first selective pick in the orchard, removing all the larger fruit. Rows were used as replicates. There were six male pickers experienced in conventional picking on the laborer platform picking the top part of the tree, four at ground level and four experienced female sorters. None of them had prior experience on the laborer platform. Conventional harvesting was done via the tractos-and-bin-trailer-harvesting method. The conventional picking team consisted of six experienced male pickers on ladders, four experienced male pickers on the ground, four experienced female sorters, a tractor driver and a crew boss.

Trial 14: The trial was conducted in a seven-year-old 'Fortune' Japanese plum orchard. Harvesting took place on 21 January 2014 as the first selective pick in the orchard, removing only the larger fruit. Rows were used as replicates. There were six male pickers experienced in conventional picking and a driver on the laborer platform picking the top part of the tree, four at ground level and no sorters. Conventional harvesting was done via the tractors-and-bin-trailers-harvesting method. The conventional picking team consisted of six experienced male pickers on ladders, four experienced male pickers on the ground, no sorters, a tractor driver and a crew boss.

Statistical analysis

Data were subjected to one way Analysis of Variance (ANOVA) by General Linear Methods using SAS Enterprise guide version 5.1 (SAS Institute Inc. Cary, North Carolina, United States of America). Where significant differences occurred ($p \leq 0.05$), means were separated by the Least Significant Difference (LSD). Single degree of freedom, orthogonal contrasts were fitted for harvesting method in trials 7, 8, 9 and 14. Covariate analysis showed that fruit mass had no significant influence on productivity outputs.

Results

Results for trials 1 to 14 are provided per trial in Table 5 to 18.

Productivity measurements

In trials 1 to 3, 5, 6 and 10 to 14 there were no significant differences between the harvesting systems or platform and conventional picking teams in terms of harvest productivity outputs (Table 5 to 14) while in trial 4 on the 'Abate Fetel' pears, the conventional team had a significantly higher $kg \cdot hour^{-1}$ output than the harvesting system (Table 15) with a similar trend seen in the other 'Abate Fetel' trial, Trial 5.

In trial 7 significant differences occurred at $P \leq 0.10$. Conventional team 1 had the highest kg/hour output, which was significantly higher than the team on the harvesting system and conventional teams 5, 6 and 7 (Table 16). Conventional team 7 had the lowest $kg \cdot hour^{-1}$ output, which was significantly lower than conventional teams 1 and 2.

In trial 8, the five-picker-male team on the harvesting system (HSM 5) had the highest kg·hour^{-1} output, which was significantly higher than the seven-picker-male team on the harvesting system (HSM 7), the six-picker-female team on the harvesting system (HSW 6), the seven-picker-female team on the harvesting system (HSW 7) and conventional team 3 (Table 17). The HSM 7 team had the lowest kg/hour output, which was significantly lower than all the other teams except for the HSW 6 team.

In trial 9, conventional team 1 had a significantly higher kg/hour output than both teams on the harvesting systems and the other two conventional teams (Table 18). The HSW 6 team had the lowest kg·hour^{-1} output, which was significantly lower than all three conventional teams, but not lower than the HSM 5 team.

Adapted orchard

Table 19 shows the yields recorded for the adapted and non-adapted parts of the 'Golden Delicious' orchard used in trial 8. In the 2012/13 season, yield was decreased by 6.4 ton ha^{-1} and for the 2013/14 season it was decreased by 28.4 ton ha^{-1}.

Picking efficiency

In trial 8, HSW 6 had a significantly lower actual picking rate than HSM 5 and Conventional teams 1 and 2 (Table 17). HSW 6 and HSM 5 had significantly lower potential picking rates and percentage inefficiency than conventional teams 1 and 2. In trial 14, there was no significant difference between the actual and potential picking rates of treatments and also no significant difference between the percentage inefficiency of different treatments (Table 14).

Discussion

Factors influencing productivity of workers on harvesting systems and platforms

Team selection and labor related factors

The time it took for the workers to get used to working on the harvesting system depended on the communication skills and style of the foreman and managers as well as the skill and understanding of the workers. The language barrier between Afrikaans and Xhosa was a problem in some cases with the crew boss and managers struggling to fully explain the concept of the harvesting system to the pickers. In the long run, the average output of the team on the harvesting system may increase as the team starts to optimize their work strategy and grow comfortable on the machine. This tendency was seen in trials 6 and 14 (Figure 4 and 5). This is likely to happen in small increments and over a long period of time and it is difficult to say whether the final level of productivity will be substantially higher than the current conventional level of productivity.

Attention should be given to the team selection process when using a harvesting system or platform. The slower pickers in the team tend to hold back the faster pickers, which contrasts the argument of Robinson and Sazo (2013) that the faster pickers will encourage the slower pickers to work faster. The slower pickers frustrated the faster pickers especially when picking at piece rate and this led to tension between pickers in many of the trials and a very negative atmosphere in the team. The workers asked that in the future they should be made part of the team selection process in order to end up with a team that works together well. Elkins et al. (2010) found that allowing pickers to pick their own team to work on a harvesting system led to a level of productivity higher than conventional harvesting teams.

The operator of the harvesting system plays an important role in the overall productivity of the team. Under varying orchard and crop load conditions, as was the case in many of the trials, the operator had to adjust the groundspeed of the machine the whole time so that workers could remain picking for the maximum length of time. Whereas with uniform tree shape and crop load distribution, the machine should be able to move more continuously. In the case of the machine stopping, the operator must try to do so in such a way that each picker still has fruit left to pick. The machine must be back in motion before the pickers are done otherwise a situation arises where the pickers wait for each other to finish before asking the operator to put the machine back in motion again.

In trial 11 the same team as in trials 5 and 10 worked on the harvesting system. By the time of the trial, pickers were frustrated with the restrictiveness of the machine and they knew they were making less money on the machine than they would have made in the conventional team. This gave the workers a negative attitude toward the harvesting system and discouraged them to work to their full potential. On the other hand, the inexperienced female team, with none of the members having any previous picking experience, was much more eager to succeed and willing to try new things and listen to advice.

In young orchards like the orchard in trial 8 where most of the fruit was borne in the lower canopy, extra pickers were needed on the ground in order to allow the constant forward movement of the harvesting system. In certain parts of the orchards, the tree shape justified an extra picker at ground level as was the case with the HSW 7 team. The HSM 5 team obtained the highest productivity output in trial 8 with the HSM 7 team obtaining the lowest output (Table 17). However, the HSM 5 team output did not differ from the HSW 6 team in trial 9 (Table 18). Elkins et al. (2010) also found that picker productivity on a platform or harvesting system increased as picker numbers decreased. This is something producers need to be wary of because the natural tendency is to place the maximum number of pickers on the machine in order to replace more ladders, but in most cases this will lead to a decrease in individual picker productivity.

The fact that the individual picker could not take a comfort- or smoke break when he/she pleased was one of the major complaints from the laborers. On the other hand, this gives the producer or manager much more control over how long and when breaks are taken if the operator of the machine takes responsibility for it. Picking fruit can be a very monotonous job, especially on the machine where laborers don't even walk or climb ladders. Observations made during this study revealed that with such monotony, picking mistakes and improper technique regularly occur when pickers lose focus. Therefore producers might benefit from breaking the monotony of picking. This can be done by e.g. the installation of a radio on a harvesting system (Warner, 2013) and some producers claim that regular forced breaks can also boost labor productivity (Warner, 2014).

Crop distribution

Uneven crop distribution causes a drop in harvesting productivity because individual pickers do not have the same number of fruit to pick irrespective of where they are stationed on the harvesting system or platform. Crop load can be unevenly distributed on individual trees from top to bottom or from side to side as well as across rows from side to side. If one picker has more fruit to pick he slows down the whole team because all the pickers are restricted to the harvesting system or platform. Uneven fruit and workload distribution can be caused by selective picking, uneven tree height and shape, row orientation and natural irregular fruit set as will be discussed. When doing the first pick on cultivars selectively picked on color, e.g. 'Cripps' Pink' apples (Trial 10), the majority of the fruit is removed from the outer and upper canopy, thus the pickers on the topmost platform generally have more fruit to pick.

This also disturbs the crop load distribution for the subsequent picks because most of the picking then has to be done in the lower canopy. With young blocks, most of the fruit is situated in the lower canopy with very little and erratic fruit set in the upper canopy as was the case in certain parts of the 'Reinder's Golden Delicious' orchard in trial 8. In trial 9 on 'Red Chief' apples most of the fruit was situated in the upper tree canopy because of the closed vase shape of the trees. Row orientation influences the amount of sunlight intercepted by the different sides of the trees (Jackson and Palmer, 1972) and therefore may have an influence on fruit set and color development of fruit (Barritt et al., 1991; Campbell and Marini, 1992). This may cause differences in crop distribution leading to pickers on the one side of the machine having more fruit to pick than the pickers on the other side.

The conventional way of harvesting gives producers some adaptability in dealing with uneven crop distribution. Even though pickers form part of a picking team, they function as individuals who can adapt and focus on heavily cropped trees or areas without affecting the pace of any other picker. Fridley (1977) found that even fruit distribution has the potential to increase the harvesting productivity of conventional pickers as well because it encourages an organized work manner. On harvesting systems such as the ones used in trials 1 to 12, pickers could not move around and help each other out as necessitated by the crop load distribution. In contrast, with the platforms used in trials 13 and 14, laborers were more mobile to help out where crop load was heavier. In order to avoid productivity loss due to the restrictive nature of the harvesting systems, producers will have to grow orchards with uniform tree height, size and fruit distribution in order to provide each picker with more or less the same number of fruit to pick on their section of the tree. One could also argue that in such situations the faster pickers must be placed where the most fruit is to be picked. In reality this is difficult to achieve because teams could end up being shuffled around so much that it takes up too much time and causes a further loss in productivity.

Tree factors

Tree height and shape as well as the length and orientation of branches also impacts on harvest productivity. As already mentioned, uneven tree height and too tall or too short trees cause an uneven crop load and work load distribution that lead to inefficiencies. In trials 4 to 7 and 9 the trees were too tall to reach the highest fruit comfortably from the highest level on the harvesting system. This led to workers climbing onto the safety railings in order to reach the fruit in the top of the trees. Elkins et al.

(2010) encountered a similar problem in tall pear orchards. In the orchards where tree height exceeded 4 m, pickers on the high levels had to harvest more than half of the tree, giving them much more work than the other pickers. The harvesting systems are designed to allow pickers to comfortably reach fruit up to a height of 3.0 to 3.5 m.

Long bearing branches extending into the row hampered the continuous movement of the harvesting system down the row. McMechan (1968) also encountered this to be a problem. The harvesting system had to stop to allow pickers to shift out their individual platforms, pick all the fruit they could reach and retract their platforms before the harvesting system could move forward again. This resulted in pickers waiting for each other to finish their part of the tree before the machine could move forward without breaking or damaging the branches. The long branches are hazardous for the workers on the machine because they cannot move out of the way due to the restrictive nature of the harvesting system. In some of the trials the branches got caught on the smaller conveyor belts and on hydraulic pipes on the bin trailers causing damage to the softer metal components of the machine.

Stone fruit trees in trials 1-3 and 12-14 and the apple trees in trials 10 and 11 were much more uniform in shape, had no scaffold branches extending into the row and were low enough to allow easy harvesting. These trials, however, showed that accessibility and a more suitable tree architecture does not necessarily translate into higher productivity outputs for harvesting systems and platforms compared to conventional harvesting. In these cases, the productivity of the team on the harvesting systems and platforms was determined by the next limiting factor, which in most cases was crop load distribution. The adapted orchard in trial 8 allowed for the further exploration of this topic. When full bearing Solaxe-trained 'Golden Delicious' trees were adapted by heading back scaffold branches extending into the row to within arm's length from the trunk, yield was reduced by 6.42 $tons \cdot ha^{-1}$ in the first year after pruning and 28.42 $tons \cdot ha^{-1}$ in the second year. However, no increase in productivity was found for pickers on the harvesting system compared to conventional pickers. This was mainly due to trees being too high and bearing branches in the top part of the tree not being headed back because they were not in the way of the machine. This concentrated the majority of the fruit in the top part of the tree, which led to lower placed pickers being idle and thus decreased overall productivity. It is likely that if the same trees were further adapted by lowering tree height and cutting back the higher bearing branches, yield would be decreased too much without any guarantee of a substantial increase in productivity of pickers on the harvesting system. Furthermore, some producers are of the opinion that when tree shape is adapted to make harvesting easier for workers on the platform or harvesting system, they make it easier for the conventional pickers as well and might increase the productivity of all pickers. Thus the relative difference between conventional pickers and those on machines will stay small and inconsistent.

Orchard factors

Orchard layout and design factors such as row width, uneven row length and pollinators affect the productivity of teams on the machines. Harvesting systems and platforms are available in varying sizes and orchard row width is one of the factors that determine the suitable size of the machine. Harvesting systems and platforms used in these trials are suitable for 3 – 4 m row widths. Difficulties were experienced in some of the 4 m rows where the individual platforms had to be shifted out completely thus moving the pickers away from the side conveyors and making the picking action in itself very inefficient as will be discussed under *Picking efficiency* below.

Unequal row lengths cause inefficiencies when using harvesting systems because of the restrictive nature of the individual platforms. When the machine exited a row with the one row of trees being longer than the other, the pickers on the one side were still picking when the pickers on the other side had no trees to harvest. The same happened when entering a row with unequal tree row lengths. Even in orchards where the rows were all the same length, this restrictiveness led to idle pickers when entering or exiting a row. The pickers on the ground in front of the harvesting system first had to pick the lower fruit on the trees before the machine could move forward to allow the pickers on the machine to start picking. One could argue that the pickers that are waiting should assist the other pickers, but in reality this is impractical because it is difficult for the picker to climb on and off of the machine and when the pickers are too crowded around one conveyor belt, they tend to be in each other’s way. This point is proven by the fact that when harvesting side rows with all the pickers on the one side of the machine, productivity stays the same or marginally increases, but it does not double as one might expect. Further justification for this point is the observation made by Elkins et al. (2010) that having more pickers on the harvesting system when not warranted by the tree shape and fruit distribution, decreases the per person output like in trial 8.

In orchards where two cultivars are planted in alternating double rows (e.g. Trials 5, 10 and 11) to facilitate pollination, harvesting on both sides of the machine is only possible in every second row while the in between rows can be harvested on one side only thereby decreasing productivity. In all of the trials these single-side rows were left for the conventional teams to harvest. In solid blocks where pollinator trees are planted in every 10^{th} tree position in the row, the pollinator also affects productivity because pickers have to wait for the harvesting system to pass the tree before they have fruit to pick again. According to Robinson and Sazo (2013), solid blocks with inter-planted pollinator trees cause a smaller loss in productivity than alternate row orchards and thus they are preferred for use with harvesting systems.

In one of the 'Abate Fetel' orchards (Trial 4), rows were sloped within the row and difficulties were experienced with the offloading of the full bins. When the harvesting system was facing downhill the chain tracks on the bin trailer that pull the bin backward were too weak to move the full bin and it had to be pushed or pulled by hand, causing downtime for the pickers. When the harvesting system was facing uphill the bin slipped downhill on the chain tracks and when depositing it on the ground it nearly tipped over because of the momentum it gained on the rollers. This is, however, a machine-specific problem that could be rectified with machine modification. The Zucal Z11 harvesting system and N.Blosi laborer platform can adjust for diagonal slopes to allow the work area to stay level but the Hermes Tecno L harvesting system cannot. Difficulties were experienced in trial 4 when the Hermes harvesting system's rear wheel on the one side slipped into a hole made by tractor tracks in a wet part of the orchard. The sudden change in angle caused the bin on the turning table to slide off as well as the machine to tilt into the trees, suggesting that severe diagonal slopes or irregularities in orchard row surface may damage machinery and potentially endanger laborers.

Logistics

Although logistical problems did not cause a decrease in productivity in the trials, improperly managed logistics for transporting and loading empty bins onto the harvesting systems and the full bins out of the row can easily become a problem and cause a loss in productivity if the harvesting system or platform has to wait for empty bins. In a situation where the machine runs out of empty bins or breaks down, all of the pickers are idle and have no alternative method of harvesting. Properly managed and competent forklift and harvesting system or platform operators equipped with suitable wireless communication devices will avoid such hold-ups to a large extent.

Other

Rain and morning dew made the central conveyor wet and caused it to stall because the pulley that turns it slipped and it had to be pulled along by hand until it got drier. On the Hermes Techno L, older wooden bins with bent corner plates got caught on the bolts and wheels when passing through the trailer. These machine-specific issues were easily rectified by some slight modifications.

Many producers use bin liners in wooden bins in order to decrease rub damage incurred while transporting the fruit form the orchard to the pack house. When using the harvesting systems, the bin liners have to be installed by the forklift operator before the empty bins are loaded onto the bin trailer, otherwise the operator of the harvesting system have to install them each time an empty bin is loaded onto the turntable while holding up the whole team. The bin liners are held in place by plastic clips at the top plank of the bin, thus in windy conditions the bottom part of the liner flapped around when the bin on the turntable was still empty. On a few occasions the loose plastic got caught on in the gear assembly and on the brush of the bin filler. This caused downtime when it needed to be removed and in severe cases when the bin filler needed to be repaired. This problem was subsequently avoided by installing a shield over the brush and gear assembly of the bin filler.

Picking efficiency

The culminating result of all of the above mentioned productivity influencing factors can be seen in the effect the harvesting systems and platforms had on the potential rate of picking and the amount of time not spent picking. The restrictive nature of the harvesting systems and the misalignment between machine and orchard design led to a 30 to 50% decrease in potential picking rates for the pickers on the harvesting system in trial 8. With conventional harvesting, the potential picking rate is high because the picker only needed to move the fruit from the place where it is picked to the harvesting bag hanging at his side or in front of the picker. The harvesting bag moves around with the picker and therefore the picker does not have to look where to place the picked fruit, allowing their eyes to stay focused on the fruit that need to be picked. With the harvesting systems, wide rows and high trees forced the pickers to shift out the individual platforms as far as they can go and by doing so moved themselves further away from the side conveyor belts. The side conveyors have limited mobility and cannot move with the picker like a harvesting bag. This means that each fruit that is picked has to be moved a longer distance in the picker’s hands before being placed onto the conveyor belt and the picker must look where to put the fruit down. Jutras and Coppock (1958) encountered a similar problem when replacing picking bags with a moveable catch-frame into which pickers threw fruit. The picker on the harvesting system spent 15 to 22% more time of the day picking than the conventional picker and this allowed the pickers on the harvesting systems to obtain similar levels of daily productivity than the conventional pickers. I.e., the pickers on the harvesting systems spent a larger part of the day picking than conventional pickers, but because the potential picking rate is restricted, an overall increase in productivity is not observed with the harvesting system.

In trial 14 the pickers on the platform used harvesting bags which allowed for potential picking rates comparable with conventional harvesting as well as similar inefficiency percentages. The harvesting systems in trial 8 and the platform in trial 14 had similar inefficiency percentages whereas the conventional teams in trial 8 had higher percentage inefficiencies than the conventional team in trial 14. This indicates that simply replacing ladders with the platform does not guarantee an increase in productivity because the fact that pickers are working together as a team on the platform still led to a substantial amount of time spent not picking.

Though not included in the trials, producers who harvest very sensitive cultivars into lugs and not bulk bins have claimed substantial increases in productivity (T. Babl and G. Clack, personal communication). It is important to note that these increases are more likely related to the highly inefficient conventional harvesting with lugs. Conventional harvesting in this instance consists of laborers who are responsible for supplying pickers with empty lugs, laborers who must hold lugs for pickers on ladders to harvest into, laborers who are responsible for collecting full lugs and loading them onto a trailer and laborers who are responsible for picking. In such an operation there are massive inefficiencies. Laborer platforms replace the labor needed to carry, hold and collect lugs and therefore gets rid of the inefficiencies as well. Such increases in productivity are likely similar to increases producers would have seen when switching from lugs to bulk bins because using bulk bins eliminates the same inefficiencies that the laborer platforms eliminate. The difference is that laborer platforms allows these increases in productivity on cultivars that cannot be harvested into bulk bins.

Conclusion

When conducting applied research at orchard level, statistical significance does not always translate into realistic or practical significance. I.e., a statistically significant difference in the level of productivity of a few decimal points does not have much practical importance to a producer. However, in trials where a large absolute difference was observed without statistical significance, false negative results may have been found. In such cases the detection of statistically significant differences was prevented by few degrees of freedom for error and experimental design. Another important concept to keep in mind is the difference in productivity levels between different farms. The significance thereof for the industry relates to the fact that platforms and harvesting systems can increase productivity on farms with below average productivity levels whereas it may have no effect or even decrease the level of productivity on farms with above average levels of productivity. Thus when the use of a platform or harvesting system leads to an increase in productivity relative to conventional practice, it is important to keep in mind the absolute level of productivity of the platform harvesting system compared to another farm or industry average.

Many South African orchards are for various reasons not suitable for the implementation of harvesting systems and platforms. Even for the orchards that are suitable for machine and platform harvesting, this study has shown that there is no default solution for the industry as a whole or on farm level to decrease the labor required for fruit harvesting. Concurrent with this, Sarig (2005) concluded that research have shown that harvesting systems and laborer platforms do not increase harvesting productivity by enough to validate their use on pure economic grounds. However, the same author advises producers to consider implementing these machines for harvesting on the basis of stabilizing the workforce, enlarging the worker pool and lightning of the work load to make harvesting less strenuous for laborers. When considering these factors as well as possible productivity gains with laborer platforms for other actions in the production process, as discussed in Paper 3, some producers might find it worthwhile to invest in such machinery and some already have.

It is interesting to note that with conventional picking, 59 – 65% of the day is spent walking to and from bins and climbing ladders. This gives an indication of the potential gains that can be unlocked with better management and more efficient implementation of existing harvesting methods. According to Sarig (2005), producers should strive to optimize every action as far as possible and economically feasible with the practices already in place on the farm. This study showed that when using harvesting systems or laborer platforms, labor management practices, training and motivation is very important and team dynamics that come into play on the machines pose new challenges. A harvesting system or platform implemented in a currently inefficient harvest setup will not operate to its full potential whereas if implemented in an efficient harvest setup, it will have the greatest chance of increasing worker productivity. Furthermore, the impact of harvesting systems and laborer platforms on a specific farm will depend on the current level of productivity on that farm and this may lead to situations where some producers can justify investments made in these machines and others will not.

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Table 1: Specific orchard detail provided per trial.

Trial	Fruit kind	Cultivar	Year planted	Age	Row orientation	Aspect
1	Nectarine	Flavour Top	1991	22	North-South	Flat
2	Nectarine	Fantasia	1996	17	North-South	Flat
3	Nectarine	Fantasia	1996	17	North-South	Flat
4	Pear	Abate Fetel	1997	16	North-South	South
5	Pear	Abate Fetel	2000	13	North-South	North
6	Apple	Panorama Golden Delicious	2006	7	North-South	Flat
7	Apple	Golden Delicious	1996	17	North-South	South
8	Apple	Reinders Golden Delicious	2009	4	North-South	Flat
9	Apple	Red Chief	1990	23	North-South	West
10	Apple	Cripps' Pink	1999	14	North-South	North
11	Apple	Cripps' Red	1999	14	North-South	North
12	Japanese plum	Angelino	2005	8	North-South	North
13	Japanese plum	Laetitia	N/A	N/A	North-South	Flat
14	Japanese plum	Fortune	2007	7	North-South	Flat

Table 2: Specific orchard detail provided per trial.

Trial	Cultivar	Row width (m)	In row (m)	Trees ha^{-1}	Training system	Tree height (m)	Tree width (m)	Yield (Ton ha^{-1})
1	Flavour Top	4.0	1.5	1667	Central leader	3.5 – 3.6	1.4 – 1.8	35
2	Fantasia	4.0	1.5	1667	Central leader	3.4 – 3.6	1.4 – 1.8	55
3	Fantasia	4.0	1.5	1667	Central leader	3.4 – 3.6	1.4 – 1.8	55
4	Abate Fetel	4.0	1.5	1667	Central leader	3.7 – 4.0	1.6 – 2.0	62
5	Abate Fetel	4.0	1.5	1667	Central leader	3.9 – 4.4	1.2 – 1.8	58
6	Panorama Golden Delicious	4.0	1.5	1667	Solaxe	4.1 – 4.3	2.2 – 2.6	85
7	Golden Delicious	4.0	1.25	2000	Central leader	3.8 – 4.2	1.6 – 2.0	69/75
8	Reinder Golden Delicious	4.0	1.75	1429	Solaxe	2.5 – 3.5	1.6 – 2.8	41/40/46
9	Red Chief	3.75	1.0	2667	Closed vase	3.4 – 4.0	1.2 – 2.0	75
10	Cripps' Pink	4.0	1.5	1667	Central leader	2.7 – 3.2	1.6 – 2.2	85
11	Cripps' Red	4.0	1.5	1667	Central leader	3.0 – 3.5	1.2 – 2.2	88
12	Angelino	4.0	1.5	1667	Palmette	3.8 – 4.0	0.6 – 0.8	19
13	Laetitia	4.0	1.5	1667	Palmette	N/A	N/A	N/A
14	Fortune	4.5	1.5	1481	Palmette	4.0 – 4.2	0.6 – 0.8	34

Table 3: Specific harvest detail provided per trial.

Trial	Cultivar	Type of Picking	Monetary incentive[z]	Replications			
				Hermes	Zucal	Conventional	Type
1	Flavour Top	2nd selective	Piece	5		3	Rows
2	Fantasia	1st selective	Piece	3		3	Rows
3	Fantasia	2nd selective	Piece	10		3	Rows
4	Abate Fetel	1st selective	Piece	3		2 and 5	Days
5	Abate Fetel	Strip	Piece	4		3	Days
6	Panorama Golden	Strip	Piece	8		4	Rows
7	Golden Delicious	Strip	Piece	4		4 (6 Teams), 3 (1 Team)	Days
8	Reinder Golden	Strip	Piece	6 (HSW7),6 (HSW6)	3 (HSM7) 3 (HSM5)	6 (1 Team), 4 (2 Teams)	Days
9	Red Chief	Strip	Piece	6	6	4 (2 Teams), 3 (1 Team)	Days
10	Cripps' Pink	1st selective	Day	3		3	Days
11	Cripps' Red	Strip	Piece	3		3	Days
12	Angelino	Strip	Piece	3		3	Rows
13	Laetitia	1st selective	Day	4		4	Days
14	Fortune	1st selective	Day	4		4 (Ladders), 7 (Ground)	Rows

[z]Piece rate refers to pickers being paid a fixed price per harvested bin and day rate refers to pickers being paid a fixed price per day.

Table 4: Physical dimensions of harvesting systems and platforms used in trials.

Dimension	N.Blosi	Hermes Tecno L	Zucal Z11
Length (mm)	3000	4900	4200
Minimum width (mm)	1830	2070	1600
Maximum width (mm)	3850	3470	3000
Maximum height (mm)	2500	2875	2600

Table 5: Effect of harvesting method on harvesting productivity for selective picking of 'Flavour Top' nectarines (Trial 1).

Treatment	Bins/MD[z]	$kg \cdot hour^{-1}$
Conventional	2.73 ns	78
Harvesting system	2.58	73
p value	0.7580	-

[z]Number of 270 kg bulk bins filled per picker in a 9.5 hour manday (MD).

Table 6: Effect of harvesting method on harvesting productivity for selective picking of 'Fantasia' nectarines (Trial 2).

Treatment	Bins/MD[z]	$kg \cdot hour^{-1}$
Conventional	0.87 ns	25
Harvesting system	0.89	25
p value	0.7484	-

[z]Number of 270 kg bulk bins filled per picker in a 9.5 hour manday (MD).

Table 7: Effect of harvesting method on harvesting productivity for selective picking of 'Fantasia' nectarines (Trial 3).

Treatment	Bins/MD[z]	$kg \cdot hour^{-1}$
Conventional	2.40 ns	68
Harvesting system	3.78	107
p value	0.1485	-

[z]Number of 270 kg bulk bins filled per picker in a 9.5 hour manday (MD).

Table 8: Effect of harvesting method on harvesting productivity for strip picking of ‘Abate Fetel’ pears (Trial 5).

Treatment	Bins/MD[z]	$kg \cdot hour^{-1}$
Conventional	3.20 ns	152
Harvesting system	2.80	133
p value	0.2506	-

[z]Number of 450 kg bulk bins filled per picker in a 9.5 hour manday (MD).

Table 9: Effect of harvesting method on harvesting productivity for strip picking of ‘Panorama Golden Delicious’ apples (Trial 6).

Treatment	Bins/MD[z]	$kg \cdot hour^{-1}$
Conventional	2.95 ns	112
Harvesting system	2.14	81
p value	0.1586	-

[z]Number of 360 kg bulk bins filled per picker in a 9.5 hour manday (MD).

Table 10: Effect of harvesting method on harvesting productivity for selective picking of ‘Cripps’ Pink’ apples (Trial 10).

Treatment	Bins/MD[z]	$kg \cdot hour^{-1}$
Conventional	2.20 ns	83
Harvesting system	2.33	88
p value	0.6978	-

[z]Number of 360 kg bulk bins filled per picker in a 9.5 hour manday (MD).

Table 11: Effect of harvesting method on harvesting productivity for strip picking of ‘Cripps’ Red’ apples (Trial 11).

Treatment	Bins/MD[z]	$kg \cdot hour^{-1}$

Conventional	4.86 ns	195
Harvesting system	3.91	156
p value	0.0917	-

[z]Number of 380 kg bulk bins filled per picker in a 9.5 hour manday (MD).

Table 12: Effect of harvesting method on harvesting productivity for strip picking of 'Angelino' Japanese plums (Trial 12).

Treatment	Bins/MD[z]	$kg \cdot hour^{-1}$
Conventional	1.86 ns	84
Harvesting system	1.64	74
p value	0.5138	-

[z]Number of 430 kg bulk bins filled per picker in a 9.5 hour manday (MD).

Table 13: Effect of harvesting method on harvesting productivity for selective picking of 'Laetitia' Japanese plums (Trial 13).

Treatment	Bins/MD[z]	$kg \cdot hour^{-1}$
Conventional	1.31 ns	59
Platform	2.39	108
p value	0.0557	-

[z]Number of 430 kg bulk bins filled per picker in a 9.5 hour manday (MD).

Table 14: Effect of harvesting method on harvesting productivity for selective picking of 'Fortune' Japanese plums (Trial 14).

Treatment	Actual			Potential		Percentage
	Bins/MD[z]	kg·hour^{-1}	Fruit/min[y]	Fruit/min[x]	kg·hour^{-1}	Inefficiency[w]
Ground	4.95 ns	104	19	32 ns	174	44 ns
Ladder	3.43	72	13	30	164	56
Platform	4.57	96	18	32	171	43
p values						
Treatment	0.3985	-	-	0.9178	-	0.3842
Conv. vs HS	0.7153	-	-	0.9267	-	0.4420

[z]Number of 200 kg bulk bins filled per picker in a 9.5 hour manday (MD).

[y]Actual bins/MD rate converted into constant rate fruit picked per minute using the fruit weight.

[x]Number of fruit a picker can pick in a minute.

[w]$(1 - (\text{Actual kg·hour}^{-1} \div \text{Potential kg·hour}^{-1})) \times 100$

Table 15: Effect of harvesting method on harvesting productivity for selective picking of 'Abate Fetel' pears (Trial 4).

Treatment	Bins/MD[z]	kg·hour^{-1}
Conventional	4.03 a[y]	174
Harvesting system	2.83 b	122
p value	0.0264	-

[z]Number of 410 kg bulk bins filled per picker in a 9.5 hour manday (MD).

[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.

Table 16: Effect of harvesting method on harvesting productivity for strip picking of 'Golden Delicious' apples (Trial 7).

Treatment	Bins/MD[z]	kg·hour^{-1}
Conv. team 1	4.25 a[y]	161
Conv. team 2	4.06 ab	154
Conv. team 3	3.85 abc	146
Conv. team 4	3.80 abc	144
Conv. team 5	3.57 bc	135
Conv. team 6	3.43 c	130
Conv. team 7	3.41 c	129
Harvesting system	3.58 bc	136
p values		
Treatment	0.0516	-
Conventional vs Harvesting system	0.3904	-

[z]Number of 360 kg bulk bins filled per picker in a 9.5 hour manday (MD).

[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.10$.

Table 17: Effect of harvesting method on harvesting productivity for strip picking of 'Reinder's Golden Delicious' apples (Trial 8).

Treatment	Fruit wieght (g)	Actual			Potential		Percentage
		Bins/MD[z]	kg·hour^{-1}	Fruit/min[y]	Fruit/min[x]	kg·hour^{-1}	inefficiency[w]
Conv. 1	171 ab[v]	4.16 ab	158	15	38 a	388 a	59 a
Conv. 2	171 ab	4.11 ab	156	15	44 a	453 a	65 a
Conv. 3	176 a	3.81 b	144	-	-	-	-
HSW 6	177 a	3.66 bc	139	13	23 b	249 b	43 b
HSW 7	161 b	3.78 b	143	-	-	-	-
HSM 5	181 a	4.45 a	169	16	27 b	294 b	44 b
HSM 7	173 ab	3.12 c	118	-	-	-	-
p value							
Treatment	0.0231	0.0075	-	-	0.0005	0.0006	0.0008
Conv. vs HS	0.6463	0.0791	-	-	<0.0001	0.0001	0.0001

[z]Number of 360 kg bulk bins filled per picker in a 9.5 hour manday (MD).

[y]Actual bins/MD rate converted into constant rate fruit picked per minute using the fruit weight.

[x]Number of fruit a picker can pick in a minute.

[w]$(1 - (\text{Actual kg·hour}^{-1} \div \text{Potential kg·hour}^{-1})) \times 100$

[v]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.

Table 18: Effect of harvesting method on harvesting productivity for strip picking of 'Red Chief' apples (Trial 9).

Treatment	Bins/MD[z]	kg·hour^{-1}
Conv. team 1	6.88 a[y]	261
Conv. team 2	6.05 b	229
Conv. team 3	5.98 b	227
HSW 6	3.84 c	146
HSM 5	3.88 c	147
p values		
Treatment	<0.0001	-
Conventional vs Harvesting system	<0.0001	-

[z]Number of 360 kg bulk bins filled per picker in a 9.5 hour manday (MD).

[y]Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.

Table 19: Effect of adapting orchards for harvesting system and platform use on orchard yield (Trial 8).

Part of block	Yield (ton·ha^{-1})	
	2012/13	2013/14
Adapted	69.06	49.13
Non-adapted	75.48	77.55

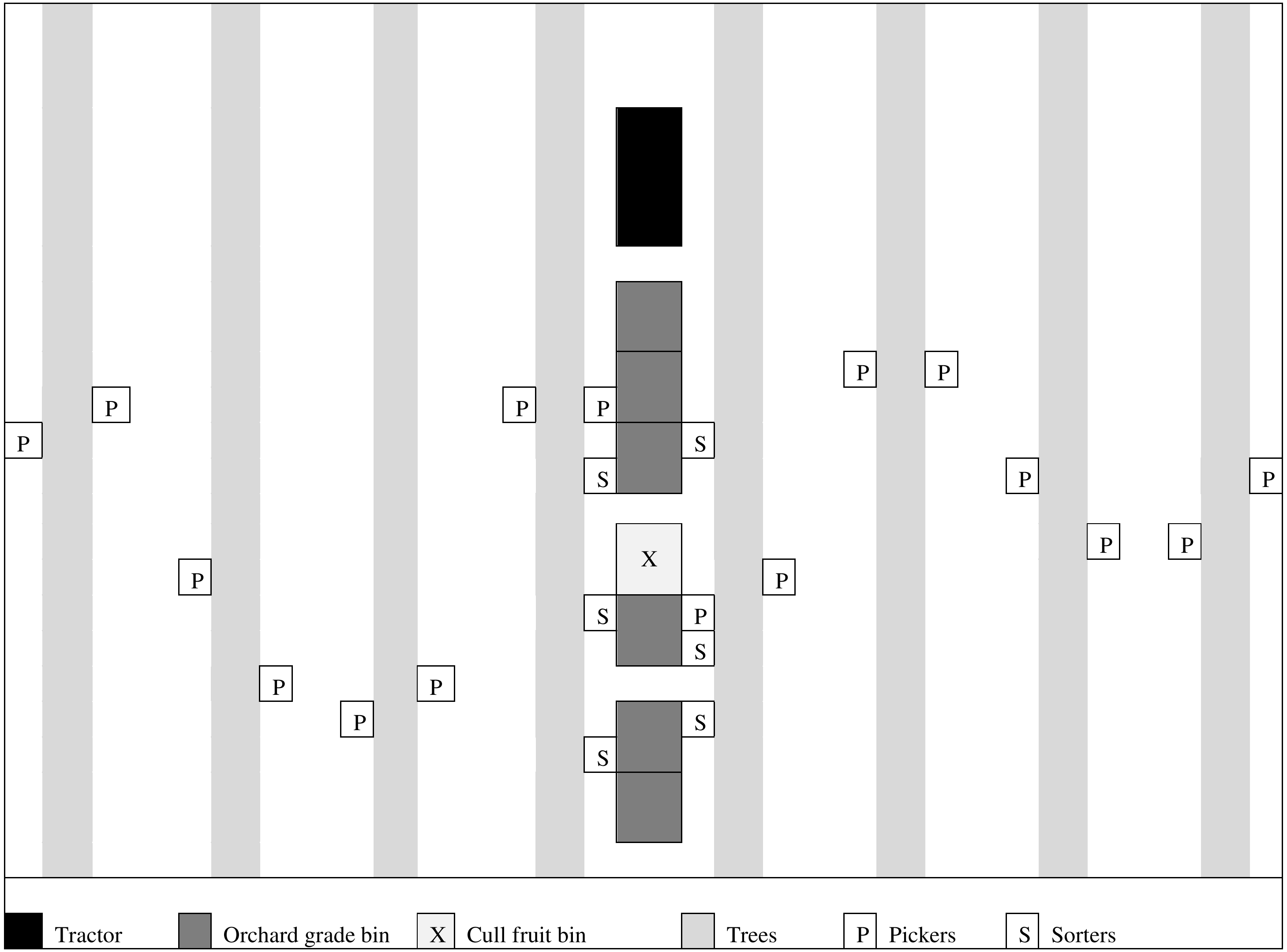

Figure 1: Tractor-and-bin-trailer-harvesting method used in trial 1 to 4, 6, 7, 9 and 12 to 14.

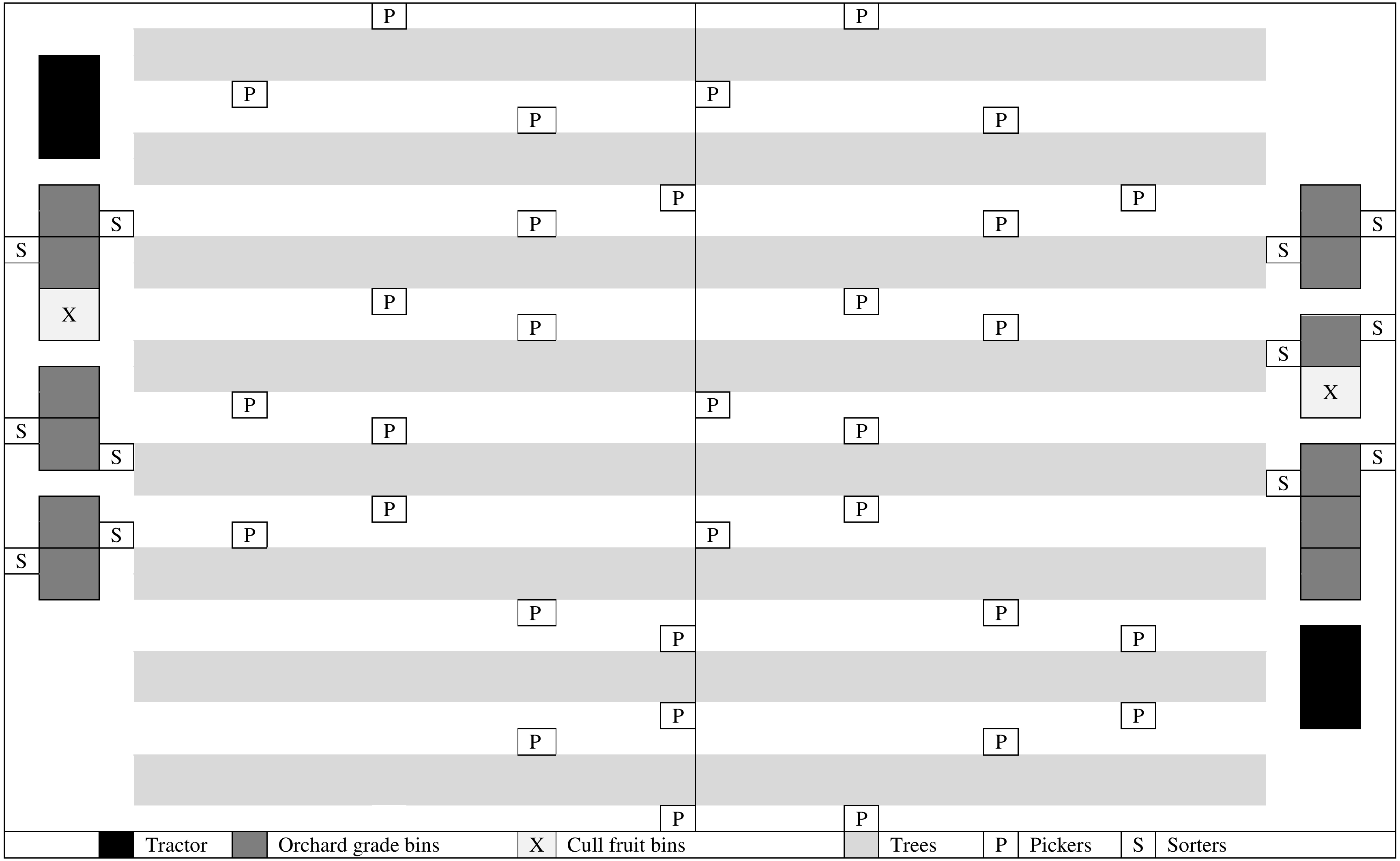

Figure 2: Tractor-and-bin-trailer-harvesting method used in trial 8 (Two separate picking teams).

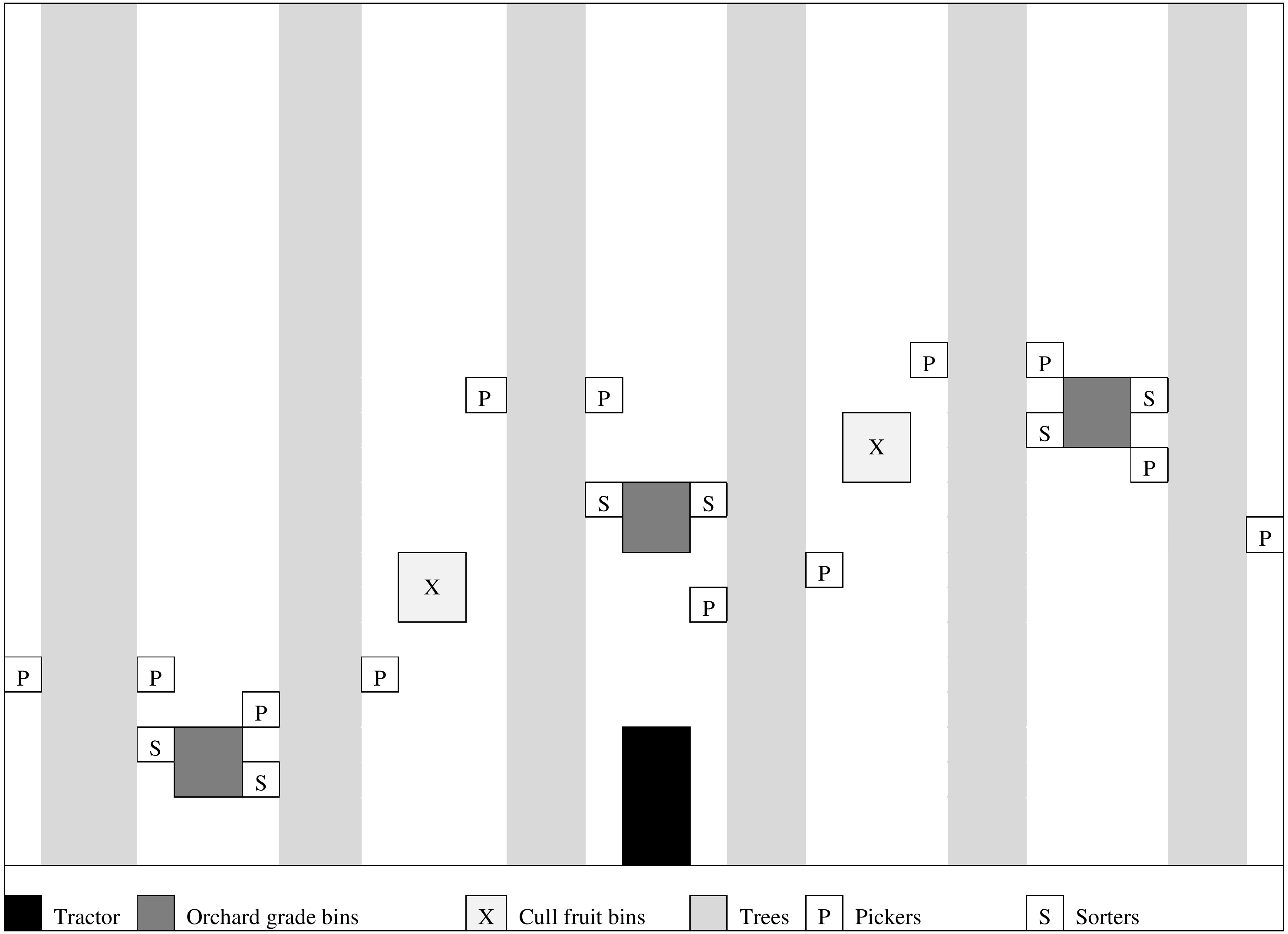

Figure 3: Bin-on-the-ground-harvesting method used in trial 5, 10 and 11.

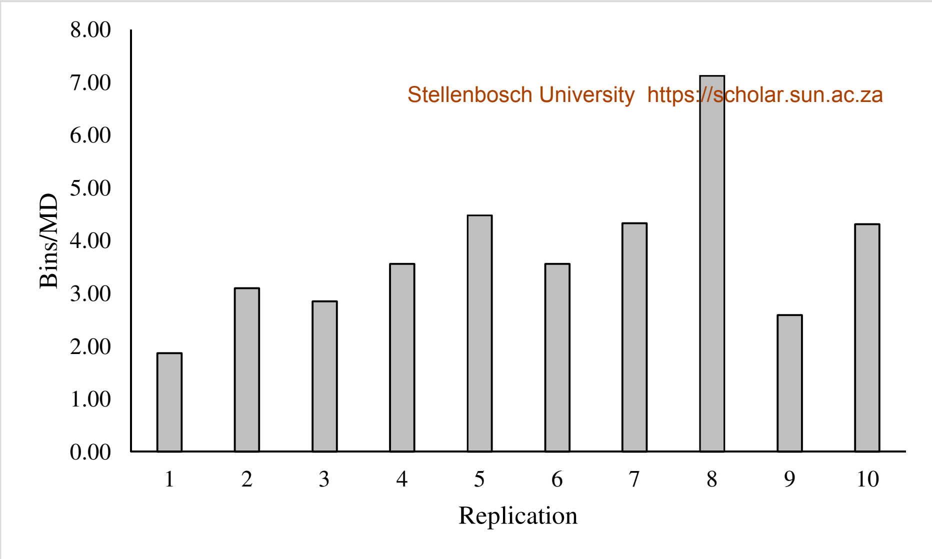

Figure 4: Individual replication bin/MD outputs of the harvesting system used for strip picking of ‘Panorama Golden Delicious’ apples (Trial 6).

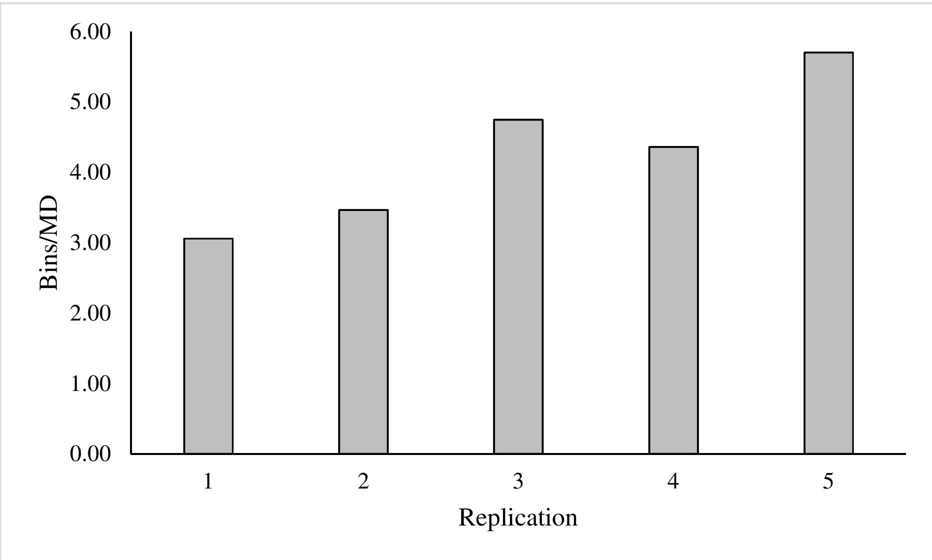

Figure 5: Individual replication bin/MD outputs of the harvesting system for selective picking of ‘Fortune’ Japanese plums (Trial 14).

PAPER 2: THE USE OF HARVESTING SYSTEMS TO DECREASE HARVEST RELATED FRUIT DAMAGE AND LOSSES

Additional index words. Harvesting injuries, mechanization, conventional practice, sorting quality, dropped fruit

Abstract

Severe harvesting injuries can lead to the culling of otherwise unblemished fruit causing a preventable loss in revenue. Experiments were carried out to assess the effect of multi-level, conveyor-type harvesting systems on the incidence of harvesting injuries, sorting quality and indirect losses incurred due to the dropping of fruit during harvesting. The aim was to evaluate the harvesting systems under standard commercial working conditions on commercial farms and therefore full day replicates were used. Fruit harvesting injury incidence of the harvesting system treatments were compared to that of conventional teams harvesting in the same orchard. A minimum of three samples of 40 to 50 fruit per treatment per day of harvesting were evaluated for harvesting injury incidence and sorting quality. The percentage incidence of common harvest injuries, viz. large bruises (>6 mm in diameter), small bruises (<6 mm in diameter), missing stems, stem punctures, broken stems, finger nail injuries and unidentifiable/other injuries were determined. Sorting quality was expressed as the percentage of juice or third grade fruit present in each sample taken. In three trials the number of fruit dropped per tree while picking was determined for the harvesting systems and conventional picking teams. There were no significant differences between treatments in terms of sorting quality in any of the trials regardless of whether the pickers on the harvesting system did the sorting themselves or whether there were extra sorters on the harvesting system. In only one trial the pickers on the harvesting system dropped fewer fruit when picking than conventional pickers. Stem punctures and broken stems were the most prevalent injuries on pears, with harvesting systems showing a tendency to decrease the incidence of harvesting injuries on pears. However the scope of improvement on a specific farm depended on the level of the injuries incurred by conventional teams on that farm. Bruising was the most prevalent injury type on apples and the effect of harvesting method on bruising incidence seemed to be cultivar dependent. On less injury prone cultivars such as Red Chief and Cripps' Red apples, harvesting systems incurred less bruising than conventional teams

but at lower productivity outputs. The scope of improvement will depend on the severity of the problem on a particular farm. On injury prone cultivars such as Golden Delicious and Cripps' Pink apples, harvesting systems incurred similar or even higher levels of bruising and total harvesting injuries than conventional teams at similar productivity outputs. The mechanical bin-filler was identified as the main source of harvesting injuries originating from the harvesting system itself. Much optimization in terms of machine design is needed for harvesting systems to handle injury prone cultivars and varying fruit size more sensitively in order to decrease the injuries caused by the harvesting system. Even if this is achieved, producers will still have to train and incentivize laborers to handle fruit carefully when removing it from the tree in order to limit harvesting injuries originating from the picking action itself.

Introduction

In an attempt to decrease harvest related fruit damage, producers are seeking to mechanize the harvesting operation. Injuries incurred during harvesting determines the physical appearance of fruit, which has an impact on the value of the end product, i.e. all the other quality parameters can be up to standard for the fruit to be of fresh market export quality but a large bruise or skin puncture can lead to the culling of that particular fruit (Lewis et al., 2007). These strict quality parameters for fresh market fruit are determined by the consumer demand for cosmetically perfect fruit (Sarig, 2005). Although focusing more on fully mechanized fruit harvesting, Kader (1983) states that proper management procedures such as harvesting at optimum maturity, ideal weather conditions as well as training, monitoring and informing workers to a large extent determine the quality of the harvested fruit. Furthermore, the harvesting operation and the handling of harvested fruit also have an impact on postharvest deterioration rates by means of the amount and severity of injuries as well as the time it takes to get the harvested fruit to the pack house and the conditions under which it gets there (Kader, 1983).

Data form commercial packhouses in the major Western Cape fruit production areas show that harvesting related injuries on apples for the 2013/2014 season ranged from 10.7% to 13.6%, with a five year average of 12.6%, consisting mainly of bruising and skin punctures. For pears it was approximately 7.0% for the 2013/14 season, with a five year average of 8.3%, consisting mainly of skin punctures. Using 2013 injury levels and prices from HORTGRO (2013), with the assumption that all of the injured fruit were export quality fruit downgraded to processing grade quality. For apples this translates into a loss in revenue of R986 million (R1087 per ton) of which R129 million (R143 per ton) can be salvaged by sending the fruit for processing. For pears it means a loss in revenue of R279 million (R735 per ton) of which R42 million (R110 per ton) is salvageable. These figures highlight the importance of minimizing injuries occurred at harvest.

The manufacturers of the harvesting systems used in this study claim that the mechanical handling of harvested fruit decrease the amount of harvesting injuries because there is less handling of fruit than with conventional harvesting (Frumaco Europe, 2014; Meccanica Zucal, 2014). In a trial on pears, Elkins et al. (2010) reports that using a conveyor-type harvesting system decreased the level of stem injuries by 8% compared to conventional harvesting. Contrary to this, most literature shows that vacuum- and conveyor-type harvesting systems incur harvesting injury levels comparable to that of conventional harvesting and with no consistent or significant differences (Elkins et al., 2010; Peppelman et al., 2006; Peterson, 2005a; Schupp et al., 2011). This is one of the reasons why producers in the USA have been slow to adopt harvesting systems (Robinson et al., 2013).

Early versions of mass removal/fully mechanized harvesters caused unacceptably high levels of damage to fruit because of fruit contact with tree limbs, poorly padded surfaces, occurrence of fruit to fruit contact and poor conveyor and bin filler design. These damages ranged from 4.6% to 26.2% for the harvesting of plums (Mehlschau et al., 1977) and in some cases on apples up to 40% of fruit were severely damaged (Peterson et al., 1994). Taking into account damage to fruit and overall harvester efficiency, at most 60% of the total crop would be eligible for sale on the fresh market (Peterson et al., 1994). This is primarily why producers never widely adopted this technology for harvesting of fresh market apples (Peterson et al., 1994; Shepardson et al., 1970). A more sophisticated and adjustable harvester suitable for Y-trellised trees and developed by Peterson and Wolford (2003) resulted in 71 to 90% of apples suitable for fresh market. Even with the improved technology, the fact that mass removal harvesters were not selective as to which fruit are removed counted against them when considering the harvesting of cultivars with variable fruit ripening (Peterson, 2005b).

Researchers developed automatic bruise detection technology for mass removal harvesters in an attempt to offset the economic loss of damaged fruit by labor savings in terms of handling, sorting and grading together with the savings from a gain in harvesting productivity (Shepardson et al., 1970). Elkins et al. (2010) also sees this as one of the factors that could lead to a more rapid adoption of modern harvesting systems. Gutiérrez et al. (2012) reports on a conveyor type harvesting system that has a two row weighing and color assessment system that inspects fruit individually and sort them into different bins. Oxbo International Corporation (Kingsburg, California, United States of America) has developed a vacuum type harvesting system with similar sorting capabilities (Warner, 2012).

Quality factors that are not mentioned in any of the literature cited are the damage done in terms of the number of fruit dropped, damage to fruit on the tree when picking selectively and the accuracy of selective picking. The number of fruit dropped when picking is of great concern to producers because many of the fruit are of export quality and once dropped it becomes cull fruit which translates into a loss of income. If only one class one fruit with a mass of 130 g is dropped per tree in an orchard planted 4 m by 1.5 m it could lead to a loss of 217 kg/ha of fruit with a value of ≈R 1800 of which ≈R250 can be salvaged if the fruit is sent for processing.

Variable fruit maturity and with it selective picking pose some challenges with the conventional harvesting methods. Producers are of the opinion that during selective picking, the movement and placement of ladders, which requires pickers to put the stand of the ladder through the tree in order to reach inside fruit, bump fruit off the tree and damage some of the fruit that is left on the tree to ripen or color and that harvesting systems and platforms could prevent this by moving alongside the tree (E. Heydenrych, Personal communication). Another aspect to selective picking that indirectly translates into potential lost profit is when fruit are incorrectly picked or left on a tree. If fruit that do not have enough color are removed during the first pick, it will be culled at the bin, whereas if the fruit was left on the tree it could have developed more color under appropriate weather conditions and would not have been culled. The same concept applies to fruit being selectively picked on size. On the other hand, when fruit that should have been picked is not removed, it could become overripe or damaged by adverse weather leading to the culling of that particular fruit.

The aim of the study was to determine whether harvesting systems can significantly decrease the amount of damage incurred at harvest time compared to conventional harvesting by ladder. In doing so it could justify the capital investment needed for the machine without a gain in productivity or necessitate a smaller gain in productivity to economically justify the machine. For the scope of this study the damage incurred at harvest time consists of the level of harvesting injuries as well as indirect losses due to dropped fruit.

Materials and methods

Production areas

Seven trials were performed on farms in various deciduous fruit production regions in the Western Cape, South Africa. Trials 1 and 3 to 5 were carried out on Paardekloof in the Witzenberg Valley (33°15' S, 19°15' E) and trials 2, 6 and 7 on Oak Valley Estate in Grabouw (34°9' S, 19°2' E). The trials were done concomitantly with the productivity study trials in Paper 1 and can be referred to for specific orchard and trial information.

Experimental design

Harvesting systems were assessed under standard commercial working conditions. Full day replicates were used in all seven trials. A formal trial layout would have disrupted the conventional harvesting process because the harvesting systems and platforms harvested the trees only on one side requiring another pass in the adjacent row to harvest the remaining side. In contrast, the conventional teams harvested rows of trees on both sides in one pass. For this reason and as well as to prevent unnatural competition between workers, the harvesting systems and platforms were evaluated in separate sections of orchards. In trials 1 to 7 the Hermes Tecno L™ harvesting system (Hermes, Gargazonne, Italy) was compared to conventional harvesting methods. In trials 4 and 5 the Zucal Z11™ harvesting system (Meccanica Zucal, Romeno, Italy) was added to the evaluation.

Treatment descriptions

Conventional practice

Conventional harvesting for trials 1 and 3 to 5 was done with the tractors-and-bin-trailers-harvesting method (Figure 1). Picking teams were made up of 16 experienced male pickers, six experienced female sorters, two tractor drivers who also picked when they were in the orchard and one foreman/crew boss. Pickers worked together in pairs to harvest a row of trees, one picker on each side of the row. Each picker was equipped with a ladder and harvesting bag. When emptying full harvesting bags, pickers had to walk to the tractor-trailer combination, which was parked in between the two middle rows of all the rows simultaneously harvested (Figure 1). The tractor with trailers intermittently moved forward as the pickers progressed down the rows in order to keep walking distance to a minimum. The six sorters continuously removed cull fruit from the orchard grade bin and placed it into a cull fruit bin also on one of the bin trailers. Each picking team had two tractors with three trailers each; a three-bin trailer followed by two two-bin trailers. When the pickers filled all the bins on one tractor-trailer combination, it was driven to the loading area where full bins were replaced with empty bins that were then taken to the pickers. Whilst one tractor was at the loading area, pickers emptied their bags into the bins on the other trailers and the process repeated itself. Throughout the orchard there were openings in the rows spaced 20-30 meters apart, allowing the pickers to walk across the rows to get to the bin trailers. The orchard used in trial 3 had no openings and the tractors were parked at the end of the rows as shown in Figure 2. Pickers had to walk down the row to empty their bags. The rows were harvested only halfway from one end of the orchard with the remaining half harvested from the opposite end.

Conventional harvesting for trials 2, 6 and 7 was done with the bin-on-the-ground method (Figure 3). Picking teams were made up of 12 experienced male pickers, six experienced female sorters, one tractor driver and one foreman/crew boss. For each team there was one tractor with a rear-mounted forklift (far-lift) that transported the bins out of the orchard to the nearest loading area. The same tractor was responsible for supplying the pickers with empty bins placed ahead of them in the row. Pickers worked together in groups of four to harvest two rows at a time with one picker on each side of a tree row. The four pickers working together emptied their bags into a bin placed between the two rows they were harvesting. Two sorters per four man team removed all the cull fruit from the orchard grade bin and put it into a separate bin placed in the adjacent row. The tractor with the forklift moved the bins of each four-man team down the row as they progressed, thereby minimizing the distance to be walked.

Harvesting systems

Conveyor belt type harvesting systems mounted on self-propelled multilevel platforms were used in all seven trials. The number of pickers on the harvesting system varied according to orchard and crop conditions, which will be discussed for each trial. In most of the trials, six pickers worked on the harvesting system, i.e., two pickers on the ground in front of the machine, one picker on each side of the machine at mid-level on separate platforms and one picker on each side of the system at the rear of the machine also on separate platforms. All four platforms could hydraulically adjust sideways allowing the picker to get closer to the tree. The two lower platforms could manually adjust vertically with the two higher platforms at the back able to hydraulically adjust vertically allowing pickers to pick at a comfortable height. Each one of the four platforms had an adjustable conveyor belt arm with another two conveyor belts extending in front of the machine for the workers picking from the ground. Pickers placed picked fruit onto the conveyor belts, which then deposited it onto a large central conveyor belt that took the fruit to the mechanical bin filler that automatically filled the bins. Bins stood on a rotating platform with the bin filler lowered into the bin. As the bin filled, a sensor automatically lifted the bin filler until an alarm went off signaling that the bin was full. Full bins were discharged either directly onto the ground with the Zucal Z11 or via the bin trailer towed behind the Hermes Tecno L. An off-road forklift (for trials 1 and 3 to 5) and a tractor with a rear mounted forklift (for trials 2, 6 and 7) were used to take the bins out of the row. The operator loaded empty bins from the bin trailer onto the rotating table. For trials 1 and 3 to 5, sorting was done by the pickers whereas in trials 2, 6 and 7 it was done by an extra worker standing next to the central conveyor belt. On the Hermes Tecno L, cull fruit was put into a separate container that s fixed on the harvesting system and on the Zucal Z11 it was put into a bin loaded on a fork on the front of the machine.

Harvesting injury assessments

The harvesting injury and sorting quality assessments for the trials 1 and 3 to 5, performed on Paardekloof, were done by the quality control laboratory staff of the farm. One orchard grade bin from each tractor-and-bin-trailers combination was assessed, i.e. for conventional harvesting one out of every five orchard grade bins were assessed and for the harvesting systems one out of every three to five orchard grade bins were assessed. Samples of 50 fruit were taken from each assessed bin at the loading bay. The harvesting and sorting quality assessments for trials 2, 6 and 7, performed on Oak Valley Estate, were done at the Department of Horticultural Science at Stellenbosch University. Three bins were assessed for every treatment on every day of harvesting, one bin from the morning, one from mid-day and one from the afternoon. Samples of 40 fruit were taken from each assessed bin at the loading bay.

Sampling was done by taking fruit from a location halfway between the center and one of the corners of the bin when looking from above. Samples were taken from the top to bottom in order to include fruit from the bottom and mid-section of the bin. Fruit were assessed for the incidence of common harvest injuries, viz. fresh large bruises (>6 mm in diameter), fresh small bruises (<6 mm in diameter), missing stem, stem punctures, broken stem, finger nail injuries and unidentifiable/other injuries. Injury incidence was reported as percentages, which was subsequently used to compare the different treatments.

Sorting quality assessments

The sorting quality of each harvesting method was determined from the same samples as the harvesting injury assessments. Sorting quality was determined by means of identifying the percentage of juice grade or third class fruit that ended up in the orchard grade bin. This included fruit that should have been culled for sunburn, old bruises, insect- and wind damage, size, shape and color.

Harvesting system analysis

In trials 6 and 7, one sample of 50 fruit each was taken in the morning and afternoon at the pickers, central conveyor belt and from the bin. In trial 6 it could only be done on one of the days and for trial 7 it was done for all three days. The amount of bruising, stem injuries and other injuries were determined for these samples in order to determine where injuries caused by the harvesting system originates from.

Dropped fruit assessments

In trial 1 the number of fruit dropped per tree was determined for both treatments, in trial 3 it was done for the harvesting system and one of the conventional teams and in trial 6 it was done for both treatments. The number of fruit dropped per plot of five trees was counted for five plots in the morning and five in the afternoon on each day spread out through the part of the orchard that was picked on that day. This was used to calculate the average number of fruit dropped per tree.

Trial-specific materials and methods

Trial 1: The trial was performed in a 16-year-old 'Abate Fetel' pear orchard during the first harvest pick. The orchard was adapted during winter dormant pruning in 2012 by heading back branches extending too far into the row in order to allow easier access for the harvesting system at harvest time.

Fruit with a diameter of more than 63 mm were picked during the first pick, leaving smaller fruit on the tree to gain size. Harvesting took place on 18 to 20 February 2013. Six male pickers experienced in conventional harvesting and an operator worked on the platform. Four of these men and the operator worked on the harvesting system in the previous season. The pickers did the sorting themselves. Conventional harvesting consisted of a picking team of 16 experienced male pickers, six experienced female sorters, two tractor drivers who doubled up as pickers and a crew boss. The tractors and bin trailers harvesting method was used (Figure 1).

Trial 2: The trial was performed in a 13-year-old 'Abate Fetel' pear orchard. The orchard was strip picked after it had already been selectively picked the week before to remove all fruit with a diameter exceeding 57 mm. Harvesting took place from 5 to 8 February 2013. Six male pickers experienced in conventional picking, an inexperienced male sorter and an operator who was also the crew boss worked on the platform. There was one picker stationed at each of the six small conveyor belts. None of the team members had previous experience of working on a harvesting system. Conventional harvesting consisted of a picking team of 12 experienced male pickers, 6 experienced female sorters and a crew boss. The bin-on-the-ground-harvesting method was used (Figure 3).

Trial 3: The trial was performed in a 17-year-old 'Golden Delicious' orchard. A part of the orchard was adapted for the use of the harvesting system. During dormant pruning during winter 2012, branches extending too far into the row were headed back to within arm's length from the trunk. The yield from the adapted part was compared to the non-adapted part of the orchard. The orchard was strip picked and harvesting took place on 5 to 7, 9, 11 and 12 March 2013. The team from trial 5 worked on the harvesting system and the conventional harvesting was done by seven teams that operated as described for trial 1 (Figure 1).

Trial 4: The trial was done in a four-year-old 'Golden Delicious Reinders' apple orchard. The orchard was strip picked and harvesting took place on 11 to 16, 18 to 22 and 25 March 2013. Two harvesting systems were used to perform two treatments each. On the Hermes Tecno L, seven inexperienced females harvested in a part of the orchard where trees were taller (3.0 – 3.5 m) and with a heavy crop load in their lower halves. There was an extra woman picking from the ground and the mid-level platforms were adjusted to their lowest level in order to concentrate most of the picking at the lower half of the tree. For the second treatment, six inexperienced females harvested in the part of the orchard where trees were shorter (2.5 – 3.0 m). Four women picked from the ground with two of them occasionally working from the mid-level platforms when needed. The two women on the upper platforms had to harvest the top parts of the tree. In both treatments there was a dedicated operator who was the crew boss and the sorting was done by the pickers. On the Zucal Z11, seven experienced males harvested in a part of the orchard where trees were taller (3.0 – 3.5 m). Two of these men worked on the harvesting system in trials 1 and 3 as well as the operator who also had to pick while operating the machine. In the part of the orchard where the trees were smaller (2.5 – 3.0 m) and lightly cropped, only five men worked on the harvesting system. Three men picked from the ground with two men on the harvesting system picking the upper halves of the trees. Conventional harvesting was done by three picking teams as described for trial 1.

Trial 5: The trial was done in a 23-year-old 'Red Chief' apple orchard. The orchard was strip picked and harvesting took place on 25 to 27 March as well as 2 and 3 April 2013. The same teams that harvested the second treatments of trial 6 worked on the harvesting systems. Conventional harvesting was done by three picking teams as described for trial 1.

Trial 6: The trial was done in a 14-year-old 'Cripps' Pink' apple orchard. Harvesting took place from 24 to 26 April 2013 as the first selective pick in the orchard, removing all fruit with at least 50% blush coloring as instructed by farm management. The team from trial 2 worked on the platform, with one of the pickers replaced by the sorter as well as a new, experienced female sorter and a new operator/crew boss. Conventional harvesting was done as described for trial 2.

Trial 7: The trial was done in a 14-year-old 'Cripps' Red' apple orchard. The orchard was strip picked and harvesting took place on 8, 10 and 14 May 2013. The team from trial 2 worked on the harvesting system. Conventional harvesting was done as described for trial 2.

Statistical analysis

Data were subjected to one way Analysis of Variance (ANOVA) by General Linear Methods using SAS Enterprise guide version 5.1 (SAS Institute Inc. Cary, North Carolina, USA). Means that differed significantly at $p \leq 0.05$ were separated by the Least Significant Difference (LSD). Single degree of freedom, orthogonal contrasts were fitted for harvesting method in trials 2, 3 and 4.

Results

Results for trials 1 to 7 are provided per trial in Table 1 to 7, but will be discussed per injury type for ease of reading. Bin/man/day (MD) outputs are displayed in the tables to contextualize the harvesting injury data, but are discussed in Paper 1.

Small bruises

There were no significant differences between treatments in any of the trials in terms of small bruises (Table 1-7). On the hardier cultivars such as Red Chief and Abate Fetel evaluated in trials 1, 2 and 5, the harvesting systems almost eliminated small bruises with the conventional teams also incurring very few small bruises. On the more sensitive cultivars such as Golden Delicious and Cripps' Pink evaluated in trials 3, 4 and 6 there were conventional teams with higher, lower and similar levels of small bruises compared to the various harvesting system treatments. Contrast analysis of harvesting systems vs. conventional harvesting in trials 3 and 4 showed a non-significant increase of small bruises of 0.7% to 1.7% by the harvesting systems. In trial 4 there was variation amongst the harvesting system treatments with one of the treatments incurring 2.3 to 3.2% fewer small bruises than the other harvesting system treatments. In trial 7 on 'Cripps' Red' the harvesting system incurred 5.4% fewer small bruises than the conventional team.

Large bruises

There were no large bruises on 'Abate Fetel' fruit in trials 1 and 2 (Table 1, 2) and very low incidences on the apple cultivars evaluated in trials 5, 6 and 7 (Table 5, 6, 7). There were no significant differences between treatments in trials 3, 5, 6 and 7 (Table 3, 5, 6, 7). In trial 3, all of the treatments had similar levels of large bruising (Table 3). In trial 4, conventional team 3 had a significantly lower incidence of large bruises compared to the six member female team on the harvesting system (HSW 6), the five member male team on the harvesting system (HSM 5), the seven member male team on the harvesting system (HSM 7) and conventional team 1, but did not differ significantly from the seven member female team on the harvesting system (HSW 7) and conventional team 2 (Table 4). HSM 5 had a significantly higher incidence of large bruises compared to HSW 6 and 7 and conventional teams 2 and 3, but not higher than HSM 7 and Conventional team 1. The harvesting systems significantly increased large bruises (5.1%) compared to conventional harvesting (2.9%) in trial 4 (Table 4).

Broken stems

Broken stems were found in trials 1, 2 and 6 (Table 1, 2, 6), but no significant differences between treatments occurred in any of these trials.

Missing Stems

No missing stems were found for ‘Abate Fetel’ pears in trials 1 and 2 (Table 1, 2). There were no significant differences between treatments in trials 6 and 7 (Table 6, 7). Even though the absolute level of missing stems in trial 3 was low, conventional team 2 had a significantly higher incidence of missing stems than all the other conventional treatments, but not significantly higher than the harvesting system treatment (Table 3). In trial 4, all four harvesting systems had significantly higher (1.5-4%) incidences of missing stems than all the conventional team treatments, except for HSM 7 that had a significantly higher level of missing stems than conventional team 3 (Table 4). In trial 5, both harvesting system treatments had significantly higher (2-5%) incidence of missing stems than all three conventional team treatments (Table 5).

Finger nail injuries

Minor finger nail injury occurred only in trials 3 and 4 with no significant differences between any of the treatments (Table 3, 4).

Stem punctures

Stem punctures occurred in all seven trials with no statistically significant differences between the treatments (Table 1-7). The harvesting system decreased stem punctures in ‘Abate Fetel’ pears by 1.1% in trial 1 and by 4.4% in trial 2, but treatment differences were not significant (Table 1, 2). Stem punctures were the predominant harvest injury for all treatments in pears.

Other injuries

No other injuries occurred in trial 6 (Table 6). In trials 1 to 5 there were no significant differences between the treatments in terms of other injuries (Table 1-5). In trial 7, the harvesting system significantly decreased other injuries by 3.8% compared to the conventional harvesting team (Table 7).

Total harvesting injuries

There were no significant differences in the level of total harvesting injuries between treatments in trials 1, 3, 5 and 6 (Table 1, 3, 5, 6). In trial 2, the harvesting system significantly decreased total harvesting injuries from 15.8% to 8.1% (Table 2). In trial 4, HSM 5 had the highest incidence of total harvesting injuries (16.3%), which was significantly higher than HSW 7 and conventional teams 2 and 3 (Table 4). Conventional team 3 had the lowest incidence of total harvesting injuries (3.7%) differing significantly from HSW 6, HSM 5, HSM 7 and conventional team 1. Overall harvesting systems resulted in 13.7% total harvesting injuries compared to 7.6% for conventional teams in trial 4 ($p=0.0004$) (Table 4). In trial 7 (Table 7), the conventional team had a significantly higher level of total harvesting injuries (17.4%) compared to the harvesting system (5.4%).

Sorting errors

There were no significant differences between treatments in terms of sorting quality in any of the trials (Table 1-7) regardless of whether the pickers did the sorting themselves or whether there were extra sorters on the harvesting system. Though not significant, the harvesting systems showed 3.7% and 4.1% more sorting mistakes than the conventional harvesting teams in trials 6 and 7, respectively (Table 6, 7).

Harvesting system analysis

Only the data from trial 7 could be statistically analyzed and showed a significant increase in bruising caused by the bin filler (Figure 4) resulting in a significant increase in total harvesting injuries as the fruit traveled from the hand of the picker to the bin. Although too few replications were obtained, trial 6 showed a similar trend, with additional injury also stemming from the transference of the apples from the side conveyors to the central conveyor of the harvesting system (Figure 5).

Dropped fruit

There were no significant differences between the harvesting system and conventional harvesting in terms of the amount of fruit dropped per tree for trials 1 and 6 (Table 8). In trial 3, conventional team 2 dropped significantly more fruit per tree than did the harvesting system (Table 8).

Discussion

Cultivar trends

The main injury type in both pear trials was stem punctures. The low injury level of the conventional team in trial 1 left little room for improvement, even though the harvesting system eliminated stem punctures. It is unlikely that a 1% decrease in stem punctures, would justify the cost of the machine of the harvesting system not even considering the decrease in productivity that was observed (Table 1 and 2). In trial 2 where the fruit were strip picked, the total injury levels for both harvesting methods were substantially higher than in trial 1. The harvesting system decreased the incidence of stem punctures from 9.4% to 5% on average, but the difference was not statistically significant due to large daily variation in injury levels. Although the harvesting system still caused a considerable number of stem punctured fruit, the 4.4% decrease makes a strong case for the harvesting system in terms of potential benefits gained from damaging fewer fruit if this result could be obtained consistently.

The effect of harvesting method on bruising seemed to be dependent on cultivar characteristics. Harvesting system teams incurred less bruising on 'Red Chief' and 'Cripps' Red' apples in trials 5 and 7, respectively. These cultivars are generally less prone to incur harvesting injuries, bruising in particular (J. Visser, personal communication), and a well-managed conventional team will incur very low harvesting injury levels thus once again leaving little room for improvement. With hardier apple cultivars conventional harvesting teams obtain high bin/MD outputs as was seen in trial 4 where the conventional teams picked two to three bins/MD more than the teams on the harvesting systems. Therefore, even though the harvesting systems showed a tendency to decrease injuries and more specifically bruising on these cultivars, the small margin of decrease would not justify the loss in productivity. The production manager on the farm where trial 7 took place indicated that the level of injuries caused by the conventional team (17.5% in total) and also bruising were exceptionally high, especially for Cripps' Red, a less injury prone cultivar. Injury analysis reports from the packhouse showed only a 7.4% incidence of harvesting injuries for another team in the same orchard. Bruising-sensitive cultivars such as Golden Delicious and Cripps' Pink, showed comparable or higher levels of total harvesting injuries and more specifically bruising at similar outputs/MD using harvesting systems. This concurs with the findings of Schupp et al. (2011) using a vacuum type harvesting system and Peppelman et al. (2006) using a conveyor type harvesting system. Due to the higher levels of harvesting injuries incurred by conventional teams in such cultivars, harvesting systems can have a meaningful impact in significantly lowering harvest injuries. Ironically though, the harvesting systems did not decrease the level of injuries. This can be ascribed to certain machine design shortcomings and picker inexperience.

Picker experience

The high missing stem incidence induced by the female teams on the harvesting systems can be ascribed to picker inexperience and an imperfect picking technique, which resulted in the pickers pulling on the fruit, causing the stem to dislodge. However, higher missing stem incidences were also observed with the experienced male team on the harvesting system in trials 4 and 5. This suggests that the harvesting systems might cause a picking action different from the conventional picking action on a ladder. The restrictive nature of the harvesting system may lead to the pickers pulling the hard to reach fruit off the tree, dislodging the stem from the fruit rather than to use the appropriate picking technique to remove the fruit with the stem. The significance of the high missing stem incidences is that it has the potential to increase disease susceptibility of some cultivars but there are postharvest biocontrol agents available which limits decay in susceptible cultivars (Janisiewicz and Peterson, 2004; Peterson, 2005b).

Variability

Considerable variation in harvesting injuries between teams occurred in the trials where different teams used the same harvesting method, especially on the injury prone ‘Golden Delicious’ and ‘Reinder’s Golden Delicious’. In both trials there were conventional teams with comparable as well as considerable lower injury levels compared to the harvesting systems. This variability suggests that harvesting injury levels are not solely dependent on the harvesting method, but that other factors such as team and worker mentality, mood and motivation may also play a role. For example, conventional team 3 of trial 4 is renowned on the farm as the team who incurs the lowest injury levels throughout the picking season and they are rewarded for it every year at a prize giving ceremony hosted by the farm. This shows that with proper management and training, a conventional team can have total harvesting injury levels of lower than 4% on injury prone cultivars without losing out on productivity, which is something a harvesting system or machine will not easily outperform.

Machine design

In concurrence with the findings of Peterson (2005a) and Schupp et al. (2011), the bin filler seems to be the main source of bruising caused by the harvesting system (Figures 4 and 5). The circular motion that the bin filler uses to fill the rectangular bin leads to the formations of a fruit pyramid in the center of the bin causing fruit to roll down and then hit the edge of the bin at high velocities (personal observation). There are other types of bin fillers with a set of rotating rubber pads underneath the conveyor that lowers the fruit into the bin, the fruit falls onto the soft ears which then spread them evenly in the bin. Video footage of such bin fillers suggests that they might work better with rectangular bins and might also be safer to use on machinery like this because the rotating head is concealed in the stationary bin (Brown, 2013; Van Doren Sales, 2012). However, Peterson et al. (2010) state that non-uniform filling is a concern for any rotating bin filler and that these bin filler types can cause up to 8% of additional bruising on fruit.

When working on a slope with harvesting systems without auto levelling capabilities, fruit rolls around in the empty bin as it rotates, potentially damaging the fruit. Slopes that were diagonal to the row direction caused the fruit on the central conveyor to accumulate on one side, causing fruit to fruit contact as well as an uneven stream of fruit entering the bin filler (personal observation). In orchards where trees were too tall, the pickers on the highest platforms had to set their side conveyor belts to a very steep angle causing fruit to roll down the conveyor and fall onto the central conveyor belt at high velocity.

Since the harvesting systems were developed in Europe where producers grow larger fruit, the machines might not be particularly well adapted to handle small fruit and because of this may cause damage to smaller fruit. There were instances where small fruit were seen falling through the rubber fingers of the bin filler which likely damaged the fruit it came to land on at the bottom of the bin filler (personal observation). Lewis et al. (2007) found that bruise volume of a certain apple cultivar at the same impact force increase with increasing radius at the point of impact suggesting that with the same force of impact, smaller apples will incur less bruising than larger apples. Thus smaller fruit might even be beneficial for a modified harvesting system that can successfully accommodate varying fruit sizes.

Sorting

As already mentioned, the harvesting systems were imported from Europe where producers do little or no in-orchard sorting especially when the fruit are delivered to a packhouse with a pre-sorter installed.

In the USA, 15% to 20% of tree fruit in bins are culled (Hansen, 2004) whereas in this study it ranged from 10% to 40% depending on cultivar (Data not shown). The amount of third grade fruit produced in South African orchards necessitates in-orchard sorting performed by sorters standing at the bins as they are being filled even when the fruit are delivered to packhouses with a pre-sorter. The reason for this is that some producers are far from the packhouse and cannot afford to transport culled fruit as far and as gently as orchard grade fruit and when fruit are delivered to packhouses without pre-sorters, which is currently the norm in South Africa, the cull fruit in the bins will be stored and graded with the orchard grade fruit thus generating unnecessary, additional costs (Peterson, 2005a).

Conventional practice is to have one sorter for every two or three pickers. The Hermes Tecno L harvesting system has an advantage in terms of sorting the orchard grade fruit because it has space where a sorter can stand next to the central conveyor belt. This space is however limited and close to the rotating bin, which constitutes a potential safety risk. All the picked fruit move past the sorter in a continuous flow, which makes for more comfortable sorting according to the sorters (M. van Wyk, personal communication). Ironically the sorter on the harvesting system for trials 2, 6 and 7 made more sorting mistakes than the conventional team sorters. This trend suggests that the harvesting system might benefit from a larger sorting area in order to accommodate more sorters if needed and also a roller conveyor which will rotate the fruit as they pass, giving the sorter a better view of the fruit without having to pick them up. Such modifications will however increase the cost and size of the harvesting system. Additionally, it could eliminate injuries incurred with conventional sorting when sorters have to spread out and turn the fruit to inspect them when the pickers empty their bags. In comparison, the Zucal Z11 does not have space for a sorter and sorting can only be done by the pickers.

Picking quality

Selective picking brought about some challenges when working with the harvesting systems. When selectively picking based on color, the majority of the fruit are removed from the upper part of the tree where color development is better. Because the pickers on a harvesting system are forced to work together as a team, the pickers on ground level had to wait for the top and middle pickers. One could argue that this gives the pickers on the ground more time to choose which fruit to pick, but we found that it rather created a situation where ground level pickers were prone to pick fruit without enough color out of fear of being idle or due to a loss of concentration ending up with 1.5% more green fruit picked in trial 6 (data not shown). These fruit were then culled at sorting, resulting in a potential loss of income. When selectively picking on size, the crew boss constantly had to make sure that the pickers were removing all the fruit and not just the ones that were easy to reach. When the harvesting system was set to continuously move forward, the pickers tended to go along at the pace of the machine; they would not stop the machine in order to pick all the fruit that were large enough. Thus the operator/crew boss must be very alert or the pickers must be more diligent to do a proper job.

Fruit on the ground can be due to natural fruit drop because of maturity, wind or clusters, ladders or machinery bumping fruit off in the harvesting process and pickers dropping fruit when picking. Observations made during trials suggest that the latter is the main cause of fruit drop regardless of the harvesting method. When fruit, especially apples, are set in a cluster, pickers tend to drop fruit more easily compared to when fruit are thinned to a single fruit per cluster and evenly spaced out on a bearing branch. The stem ends fit together tightly on the bourse axis. Removing one of these stems can compromise the stability of the cluster causing other stems to detach and the fruit to drop if the picker is not holding it. It can also be expected that clustered fruit could be more easily damaged because of fruit pressing against one another or being rubbed against a spur or branch when the picker tries to maneuver it into a position where the stem will break off. Whereas when fruit are evenly spaced on the branch, the picker has room to maneuver each fruit without the danger of dropping other fruit while both hands are occupied. In trial 3, the conventional team dropped twice as many fruit per tree as the harvesting system. However, after this was brought under the farm management's attention, the problem was addressed and considerably fewer fruit were dropped by the conventional team. Producers and management are aware of the problem, but because it is rarely quantified, it is hard to determine the extent to which it occurs. Thus it is a problem that could be better managed with better monitoring. When selectively picking in trial 6, the harvesting system at times bumped green fruit off the tree. However, its contribution to the total number of fruit dropped is speculated to be very low and the same can be said for fruit that were bumped off by the ladders. The solution to this is to grow trees with narrower canopies; doing so will benefit both the harvesting systems and conventional teams because pickers will now be able to put their ladders alongside the tree and not through the tree to reach the inside fruit.

Conclusion

When conducting applied research at orchard level, statistical significance does not always translate into realistic or practical significance. I.e., a statistically significant difference in total harvesting injuries of a fraction of a percentage does not have much practical importance to a producer. However in trials where a large absolute difference was observed without statistical significance, false negative results may have been found. In such cases the detection of statistically significant differences was prevented by few degrees of freedom for error and experimental design. For any system, whether managerial or technological, to substantially decrease harvesting injuries, there must first be a considerable number of injuries. It would be unrealistic to expect any system to completely eliminate harvesting injuries because of the human hand involved in the picking and handling of a sensitive and perishable product.

The data indicate that conveyor type harvesting systems have the potential to decrease stem punctures on pears if it is a significant and persistent problem on a farm. With apples there are differences in terms of the effect of harvesting method on the level of harvesting injury for different cultivars. It is evident that the harvesting system cannot handle the more sensitive cultivars with enough care to decrease harvesting injuries whereas on hardier cultivars it does tend to decrease injuries, but at lower productivity rates than the conventional teams.

Producers who struggle with high incidences of harvesting injuries can approach the problem in different ways. One approach is to diligently monitor the number and type of injuries to inform pickers in conventional teams of their level of injuries on a regular basis throughout the day, either for the team as a whole or as individual pickers. This information must then be used to motivate pickers to minimize harvesting injuries. This can be done by awarding the team with the lowest harvesting injury incidence over the season and by coupling piece rate bin prices to the level of harvesting injuries. In the USA, producers have gone so far as to implement this practice at an individual picker level (Personal communication). This way each picker can only blame themselves for the damaged fruit found in the bin. Furthermore, the information on harvesting injuries can be used to correct picking technique if certain types of injuries prevail, e.g. the high missing stem incidence in trials 4 and 5. It is also important that the pickers understand that damaged fruit leads to a loss of income and that this is the reason why producers/managers are implementing systems to minimize injuries.

Alternatively, producers can invest in the latest harvesting systems in an attempt to decrease harvesting injuries, but even this is not as simple as buying the machinery. The workers on the machine must still be informed and well trained. They should also be motivated to pick as neatly as possible in order to minimize the damage originating from the picking action itself. Furthermore, the operator and management staff should understand how to adjust and calibrate the harvesting system for different cultivars and orchards in order to minimize the amount of damage originating from the harvesting system. Even then, a decrease in harvesting injuries is not guaranteed because of machine design shortcomings and variability between cultivars.

When it comes to the quality of work being done, producers have the choice to either "police" and manage the problems to a level where they are satisfied or to create an environment that limits the cause and extent of the problem, which then at the same time lessens the demand for monitoring or allows for easier and more efficient monitoring. For example, in the case of dropped fruit, producers can either rigorously monitor the number of fruit dropped by each picker, then incentivizing them to drop fewer or they can limit the size of clusters at thinning time, which makes it easier for the pickers to pick the fruit without dropping any. The ideal solution would probably lie somewhere in between these options, i.e. applying management and farming practices that create a picker friendly work environment and tree whilst at the same time having proper monitoring and incentivizing systems in place, not only to motivate individual worker excellence, but also to identify the cause of problems experienced.

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Table 1: Effect of harvesting method on harvesting injury levels and sorting quality for selective picking of 'Abate Fetel' pears (Trial 1).

Treatment	Bins/MD	Small bruises (%)	Broken stems (%)	Stem punctures (%)	Other injuries (%)	Total (%)	Sorting errors (%)
Conventional	4.03 a [z]	0.0 ns	1.8 ns	1.1 ns	0.2 ns	3.0 ns	1.4 ns
Harvesting system	2.83 b	0.2	1.7	0.0	0.0	1.9	0.0
p value	*0.0264*	*0.2199*	*0.8770*	*0.1778*	*0.2710*	*0.2182*	*0.0637*

[z] Means followed by the same letter in a column are not significantly different at 0.05 level of significance.

Table 2: Effect of harvesting method on harvesting injury levels and sorting quality for strip picking of 'Abate Fetel' pears (Trial 2).

Treatment	Bins/MD	Small bruises (%)	Broken stems (%)	Stem injuries (%)	Other injuries (%)	Total (%)	Sorting errors (%)
Conventional	3.20 ns	1.7 ns	3.9 ns	9.4 ns	0.8 ns	15.8 a [z]	10.3 ns
Harvesting system	2.80	0.6	1.7	5.0	0.8	8.1 b	10.8
p value	0.2506	0.2746	0.1633	0.1161	1.0000	0.0447	0.8722

[z] Means followed by the same letter in a column are not significantly different at 0.05 level of significance.

Table 3: Effect of harvesting method on harvesting injury levels and sorting quality for strip picking of 'Golden Delicious' apples (Trial 3).

Treatment	Bins/ MD		Small bruises (%)		Large bruises (%)		Missing stems (%)		Finger nail injuries (%)		Stem injuries (%)		Other injuries (%)		Total (%)		Sorting errors (%)	
Conv. 1	4.25	ns	6.9	ns	3.1	ns	0.0	b [z]	0.0	ns	0.0	ns	0.2	ns	10.3	ns	2.0	ns
Conv. 2	4.06		4.3		2.9		1.1	a	0.0		0.1		0.2		8.6		1.3	
Conv. 3	3.85		3.3		3.7		0.5	b	0.1		0.2		0.3		8.0		1.0	
Conv. 4	3.80		4.0		3.2		0.3	b	0.0		0.1		0.5		7.9		0.6	
Conv. 5	3.57		5.5		2.8		0.3	b	0.0		0.0		0.2		8.8		1.2	
Conv. 6	3.43		5.4		3.4		0.2	b	0.0		0.2		0.2		9.5		1.4	
Conv.7	3.41		5.0		3.8		0.4	b	0.0		0.0		0.1		9.3		1.8	
Hermes	3.58		5.6		3.0		0.6	ab	0.0		0.4		0.1		9.7		1.0	
p values																		
Treatment	0.0516		0.0877		0.9699		0.0230		0.5681		0.2216		0.5584		0.8887		0.6552	
Conv. vs HS	0.3904		0.4481		0.7415		0.4546		0.3868		0.0128		0.3740		0.5891		0.5465	

[z] Means followed by the same letter in a column are not significantly different at 0.05 level of significance.

Table 4: Effect of harvesting method on harvesting injury levels and sorting quality for strip picking of ‘Golden Delicious Reinders’ apples (Trial 4).

Treatment	Bins/MD		Small bruises (%)		Large bruises (%)		Missing stems (%)		Finger nail injuries (%)		Stem injuries (%)		Other injuries (%)		Total (%)		Sorting errors (%)	
Conv. 1	4.16	ab [z]	5.0	ns	5.0	abc	1.0	bc	0.0	ns	0.1	ns	0.1	ns	11.3	abc	1.1	ns
Conv. 2	4.11	ab	3.3		2.8	cde	1.2	bc	0.0		0.3		0.0		7.7	cd	1.7	
Conv. 3	3.81	b	2.7		0.9	e	0.1	c	0.0		0.0		0.1		3.7	d	2.8	
HSW 6	3.66	bc	5.2		4.3	bcd	4.0	a	0.1		0.5		0.2		14.2	ab	1.8	
HSW 7	3.78	b	2.6		2.1	de	3.6	a	0.0		0.4		0.1		8.9	bcd	1.5	
HSM 5	4.45	a	4.9		7.5	a	3.2	a	0.0		0.6		0.2		16.3	a	1.6	
HSM 7	3.12	c	5.4		6.3	ab	2.6	ab	0.1		0.8		0.2		15.4	a	2.7	
p values																		
Treatment	0.0075		0.1280		0.0021		0.0016		0.3173		0.0715		0.8626		0.0020		0.3443	
Conv. vs HS	0.0791		0.2737		0.0078		<0.0001		0.1433		0.0053		0.2386		0.0004		0.8956	

[z] Means followed by the same letter in a column are not significantly different at 0.05 level of significance.

Table 5: Effect of harvesting method on harvesting injury levels and sorting quality for strip picking of 'Red Chief' apples (Trial 5).

Treatment	Bins/MD	Small bruises (%)	Large bruises (%)	Missing stems (%)	Stem injuries (%)	Other injuries (%)	Total (%)	Sorting errors (%)
Conv. 1	6.88 a [z]	0.2 ns	1.3 ns	0.5 b	0.5 ns	0.0 ns	2.5 ns	1.0 ns
Conv. 2	6.05 b	0.0	0.0	2.0 b	0.0	0.0	2.0	0.0
Conv. 3	5.98 b	1.2	2.1	2.2 b	1.0	0.1	6.7	1.4
HSW 6	3.84 c	0.0	0.1	5.5 a	1.1	0.2	6.9	1.6
HSM 5	3.88 c	0.0	0.1	4.6 a	0.3	0.1	5.1	0.6
p values								
Treatment	<0.0001	0.1562	0.2887	0.0002	0.6346	0.7497	0.2454	0.4725
Conv. vs HS	<0.0001	0.1797	0.1517	<0.0001	0.7152	0.2812	0.1676	0.5786

[z] Means followed by the same letter in a column are not significantly different at 0.05 level of significance.

Table 6: Effect of harvesting method on harvesting injury levels and sorting quality for selective picking of 'Cripps' Pink' apples (Trial 6).

Treatment	Bins/MD	Small bruises (%)	Large bruises (%)	Broken stems (%)	Missing stems (%)	Stem injuries (%)	Total (%)	Sorting errors (%)
Conventional	2.20 ns	5.4 ns	0.8 ns	0.8 ns	2.1 ns	3.3 ns	12.5 ns	11.7 ns
Harvesting system	2.33	7.1	1.3	0.4	3.3	1.7	13.8	15.4
p value	0.6978	0.3453	0.6433	0.6779	0.1012	0.2302	0.6130	0.3941

Table 7: Effect of harvesting method on harvesting injury levels and sorting quality for strip picking of 'Cripps' Red ' apples (Trial 7).

Treatment	Bins/MD	Small bruises (%)	Large bruises (%)	Missing stems (%)	Stem injuries (%)	Other injuries (%)	Total (%)	Sorting errors (%)
Conventional	4.86 ns	7.9 ns	1.7 ns	2.9 ns	0.8 ns	4.2 a [z]	17.5 a	8.8 ns
Harvesting system	3.91	2.5	0.4	2.1	0.0	0.4 b	5.4 b	12.9
p value	0.0917	0.2102	0.1012	0.2302	0.1161	0.0335	0.0384	0.3465

[z] Means followed by the same letter in a column are not significantly different at 0.05 level of significance.

Table 8: Effect of harvesting method on the amount of fruit dropped per tree while picking.

Treatment	Dropped fruit/tree		
	'Abate Fetel' (Trial 1)	'Golden Delicious' (Trial 2)	'Cripps' Pink' (Trial 6)
Conventional team	6 ns	9 a [z]	13 ns
Harvesting system	5	5 b	11
p value	0.1424	0.0441	0.3497

[z] Means followed by the same letter in a column are not significantly different at 0.05 level of significance.

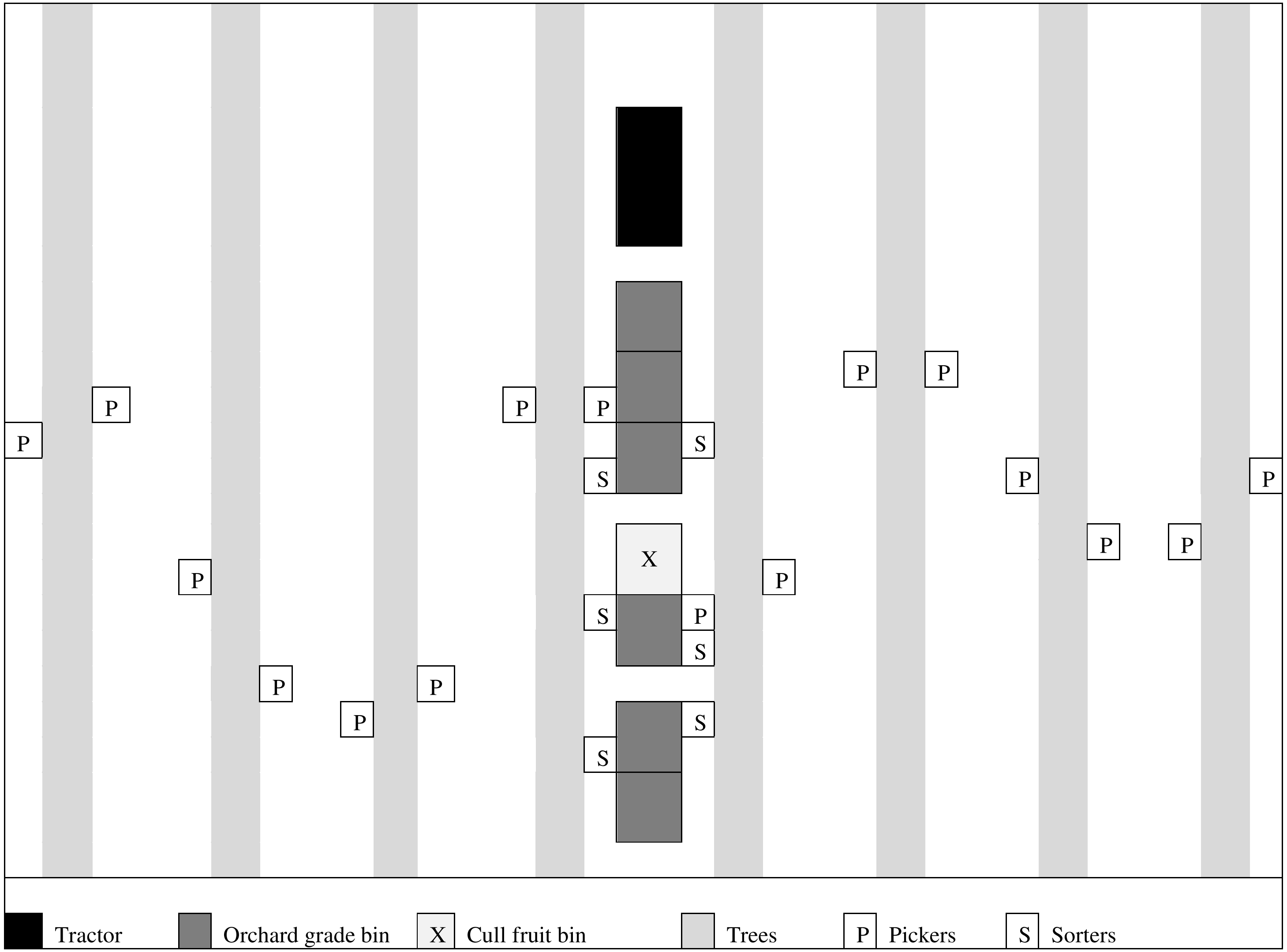

Figure 1: Tractor-and-bin-trailer-harvesting method used in trial 1, 4 and 5.

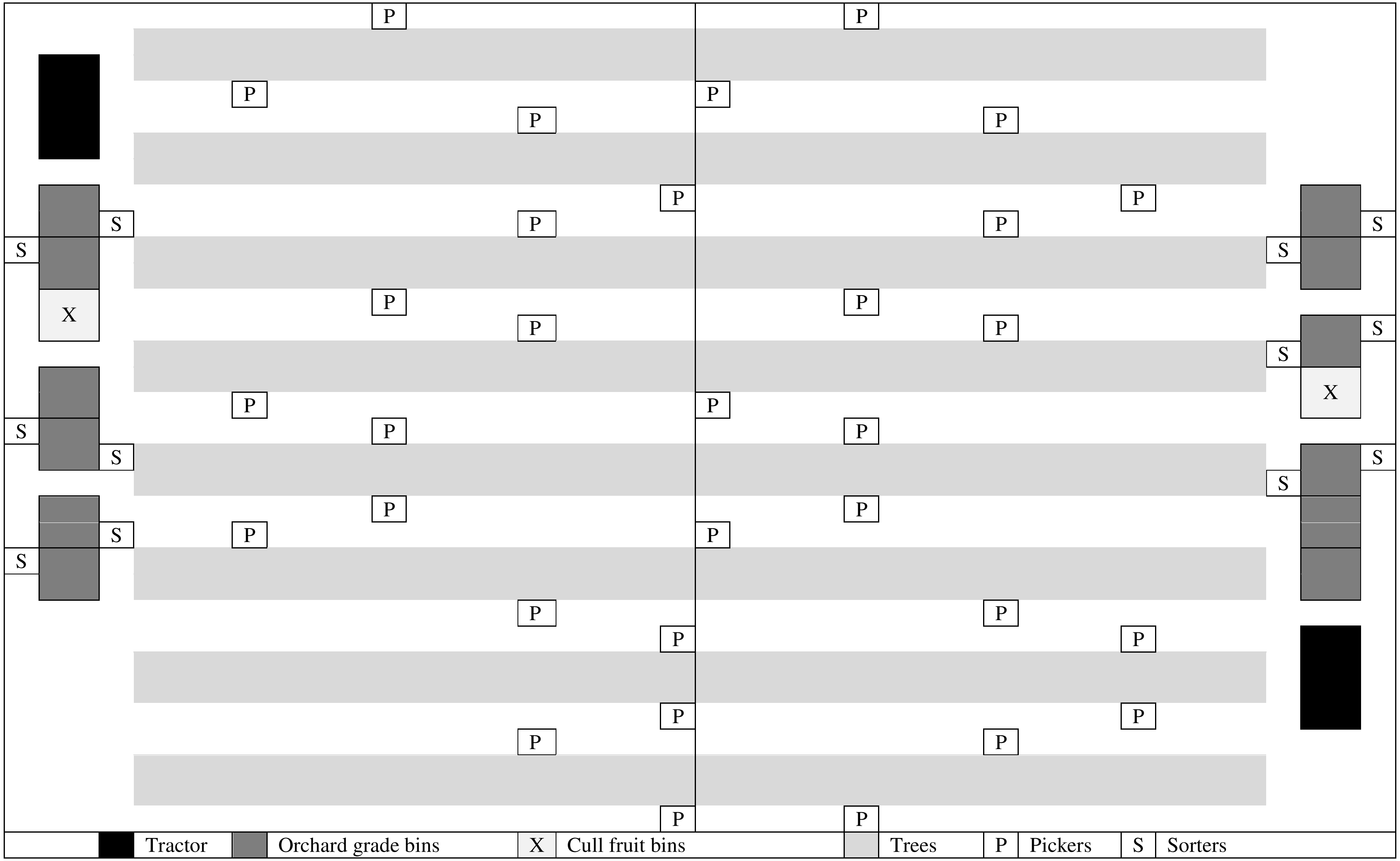

Figure 2: Tractor-and-bin-trailer-harvesting method used in trial 3 (Two separate picking teams).

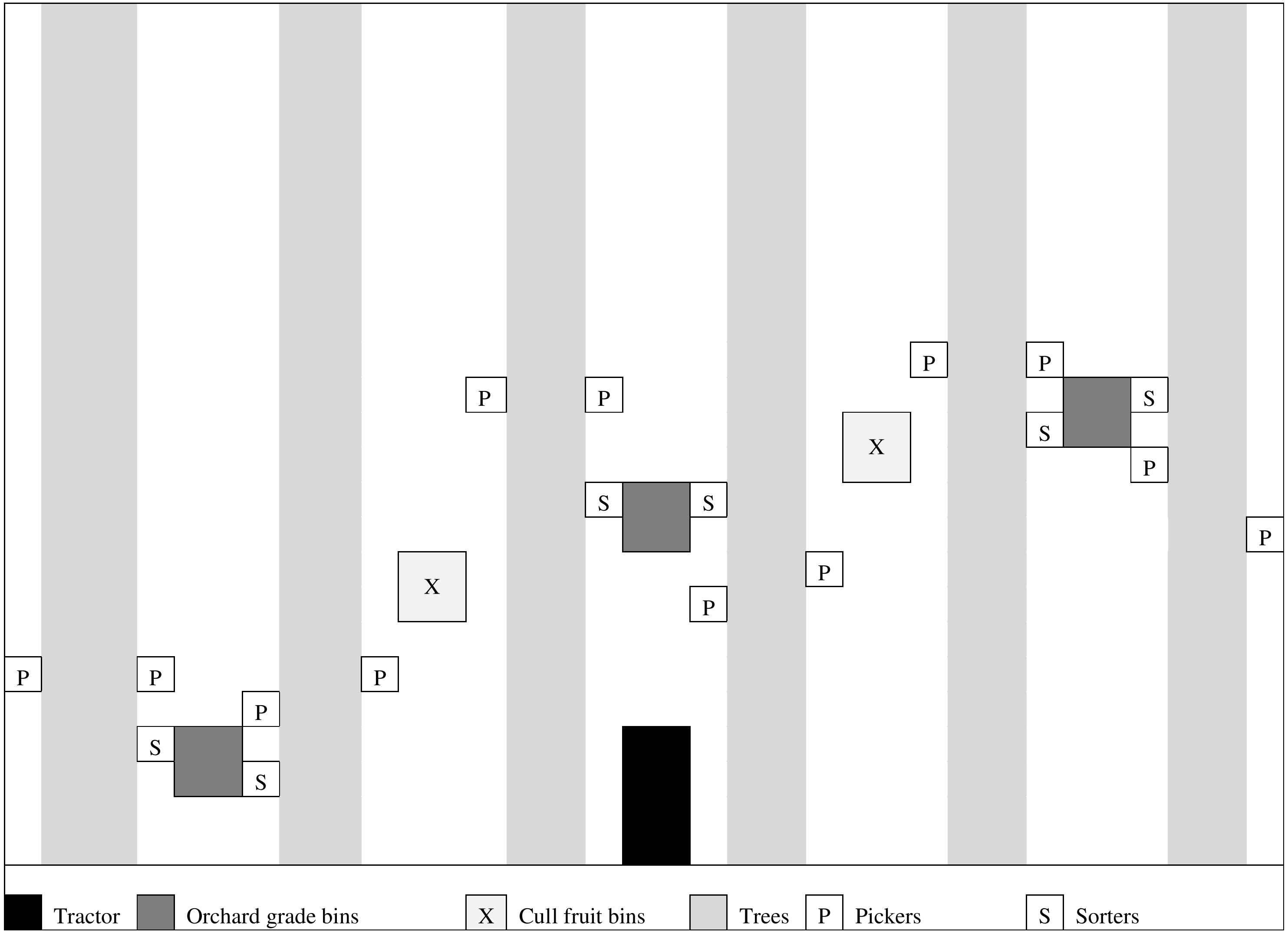

Figure 3: Bin-on-the-ground-harvesting method used in trial 2, 6 and 7.

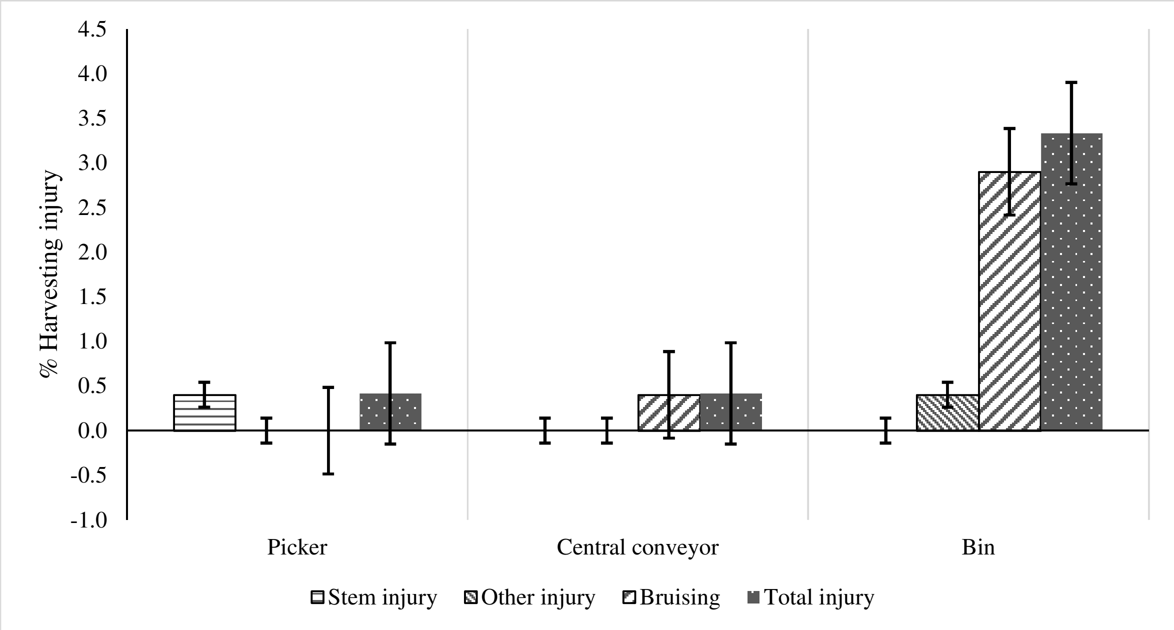

Figure 4: Accumulation of harvesting injuries from the point of picking to the bin on 'Cripps' Red' when using a conveyor type harvesting system.

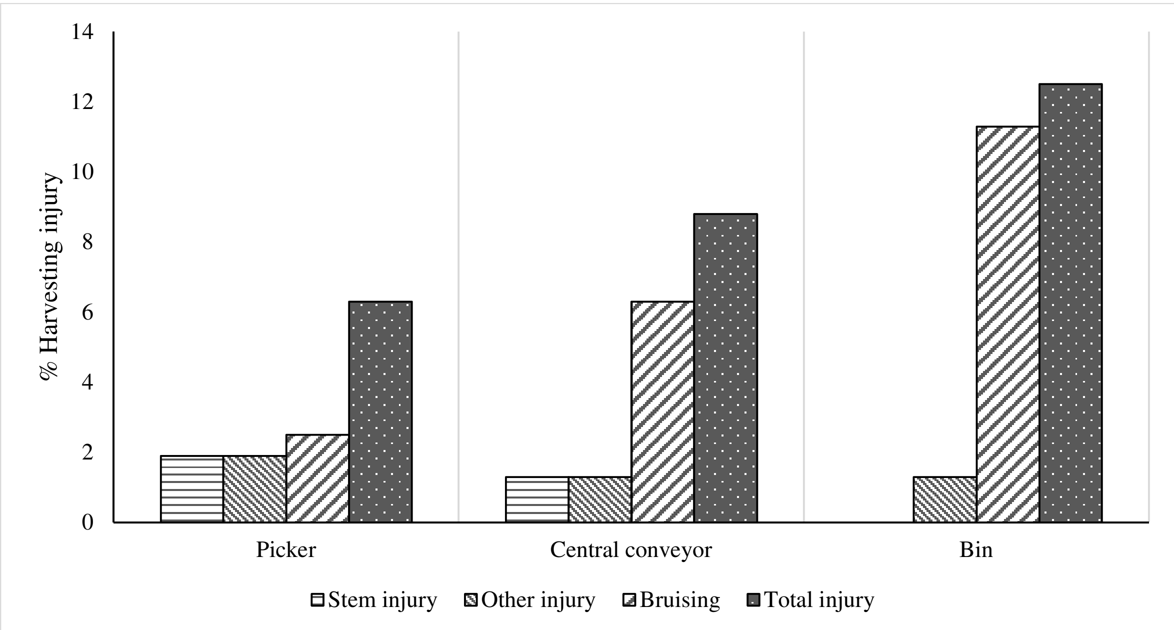

Figure 5: Accumulation of harvesting injuries from the point of picking to the bin on 'Cripps' Pink' when using a conveyor type harvesting system.

PAPER 3: THE USE OF LABORER PLATFORMS FOR PRUNING AND THINNING IN THE SOUTH AFRICAN DECIDUOUS FRUIT INDUSTRY

Additional index words. Mechanization, conventional practice, labor productivity, labor efficiency, thinning quality

Abstract

The increasing cost of fruit production creates the need for more cost-effective orchard practices on South African deciduous fruit farms and increasing the productivity of labor is one of the components focused on. Laborer platforms were evaluated in various production regions to evaluate the effect of these machines on laborer productivity during pruning and thinning of pome and stone fruit. Orchard actions where a significant amount of time is spent moving ladders relative to the time spent working on the ladders showed the greatest productivity gains when performed using platforms, e.g. summer pruning and to a lesser extent dormant pruning. The effect on dormant pruning productivity varied from a decrease in productivity to a significant increase in productivity, depending on tree architecture and pruning strategy. The effect on fruit thinning productivity varied from no effect to an increase in productivity; however, in this case cultivar and fruit set characteristics likely caused the difference as both orchards had similar tree architectures. In order to maximize productivity gains utilizing platforms, producers should aim to simplify pruning and thinning strategies. Although an increase in laborer productivity was seen in most of the trials, it is important to consider the specific orchards and circumstances under which it was achieved, because many South African deciduous fruit orchards are not suitable for the implementation of laborer platforms.

Introduction

Options to mechanize fresh market deciduous fruit production are limited when compared to mechanization options in field crop and vegetable production. The major difference between these farming systems is that most of the machinery deciduous fruit farmers employ aim to increase the efficiency of the laborers (Robinson, 2011) rather than substitute laborers completely as was seen with the advent of combine harvesters as described in Van Zyl et al. (1987).

Research on the mechanization of orchard tasks focusses on two major fields. One field is the development of machinery that substitutes labor in the orchard, such as robots, mechanical hedgers and mechanical thinners, which is beyond the scope of this study. The other field is the development of machinery, such as laborer platforms, that aid laborers in their work (Robinson, 2011). Laborer platforms are widely used in Europe and the United States of America (Sazo and Robinson, 2013). The machinery used varies from simple tractor-pulled platforms to more sophisticated self-propelled platforms and from single-laborer positioners to multi-laborer platforms (Sazo et al., 2010). Laborer platforms can be used for pruning, hand thinning, tree training, trellis construction and repair, and harvesting (Lehnert, 2013; Sazo and Robinson, 2013). The fact that the same laborer platform can be used for various tasks throughout the year, improves the cost-effectiveness of the machine (Warner, 2013). In essence, all laborer platforms replace the ladders in the orchard and therefore ease the job for the laborer, thereby allowing some laborers to perform orchard tasks that were previously inaccessible to them (Robinson, 2011; Sazo et al., 2010). Laborer platforms can also be outfitted with compressors to power pneumatic pruning tools thereby making pruning less strenuous and decreasing hand fatigue (Warner, 2013). When used properly, laborer platforms can improve the safety and comfort for the laborers on the machine (Sazo et al., 2010).

In addition to enlarging the labor pool by lessening the physicality of orchard tasks, Sazo and Robinson (2013) is of the opinion that when using laborer platforms the team is encouraged to work at the same speed to increase productivity as well as to prevent over- or under pruning and thinning. Lesser et al. (2008) reported productivity increases of 20 to 65%, depending on the task performed, when using a laborer platform compared to ladders. Tree training and harvesting showed the biggest increases in productivity with fruit thinning showing the smallest, with pruning ranging in between. Sazo et al. (2010) saw a reduction in labor costs of 27 to 30% for dormant pruning and found that there was no significant difference between the different types of platforms used. Warner (2013) found a 30% increase in pruning productivity and a similar decrease in labor costs. In their trials, Lesser et al. (2008) also found that the quality of the job done depended on the compatibility of the laborer platform and orchard design. Sazo et al. (2010) reports that as laborers gain experience on platforms, larger labor productivity gains may be seen, but this will be dependent on the team itself as well as the way the team is managed.

This study focused on the use of laborer platforms in various South African deciduous fruit orchards in an attempt to increase laborer productivity, and to determine the suitability of different current training systems and orchards for the use of these machines as well as guide producers to establish new orchards that will allow machine use in future.

Materials and methods

Production areas

Seven trials were performed during the 2012/13 and 2013/14 seasons on farms in various deciduous fruit production regions in the Western Cape, South Africa. A summer pruning trial was carried out on Kromfontein (Trial 1) in the Koue Bokkeveld (32°57' S, 19°14' E). Dormant pruning trials were carried out on Eikenhof (Trial 2) and Oak Valley Estate (Trial 3) in Grabouw (34°7' S, 19°2' E and 34°9' S, 19°2' E, respectively), Graymead (Trial 4) in Vyeboom (34°1' S, 19°7' E) and Paardekloof (Trial 5) in the Witzenberg Valley (33°15' S, 19°15' E). Fruit thinning trials were carried out on Transpalmiet (Trials 6 and 7) in Grabouw (34°15' S, 19°3' E). Specific orchard and trial information are provided in Tables 1 to 3.

Experimental design

Platforms were assessed under standard commercial working conditions. Full day replicates were used as far as possible in order to capture the realistic potential of the harvesting systems by including normal inefficiencies that might be excluded when using rows as replicates, e.g. the time it takes to move between rows, comfort breaks, etc. A formal trial layout would have disrupted the conventional process because the laborers on the platforms could only do work on one side of the tree, requiring another pass in the adjacent row to do the work on the remaining side. In contrast, laborers in the conventional teams worked on both sides of trees simultaneously. For this reason, and as well as to prevent unnatural competition between workers, the platforms were evaluated in separate sections of orchards. The trials where and the reasons why days as replicates were not used will be discussed for these trials individually. Laborer experience was documented in an informal manner as to keep answers honest and sincere. Laborers were asked to comment on team dynamics, advantages and disadvantages of the platforms as the trials were conducted.

In trials 1 to 4, the Hermes Tecno L™ multi-level platform (Hermes, Gargazonne, Italy) was compared to a conventional team performing the same orchard task. In trials 5 to 7 the Zucal Z11™ multi-level platform (Meccanica Zucal, Romeno, Italy) was compared to a conventional team performing the same orchard task. The specifications of these machines are provided in Table 4.

Treatment descriptions

Conventional practice

The size of the teams varied between farms as will be discussed for each trial. Conventional teams consisted of experienced male laborers and a crew boss for all trials except trial 8 where the conventional team consisted of experienced female laborers. Laborers worked together in pairs to prune or thin a row of trees with one person on each side of the tree. In trials 1 to 5, each laborer was equipped with a ladder and pruning shear and in trial 1 also a saw for larger cuts. In trials 6 and 7, laborers were only equipped with a ladder each. The crew boss was responsible for maintaining the standard of the work done as instructed by the producer and/or manager.

Platforms

The number and position of laborers on the platforms varied between farms as will be discussed for each trial. For trials 1 to 4, 6 and 7, the team on the platform consisted of experienced male laborers and for trial 5 the team consisted of experienced female laborers. The platforms used in trials 1 to 5 were equipped with a compressor and pneumatic pruning shears. In trial 1, the platform was also equipped with two pneumatic chainsaws for larger cuts. In all the trials the platform operator was the crew boss of the team and together with the crew boss of the conventional team was responsible for maintaining the standard of the work done as instructed by the producer/and or manager.

The Hermes Tecno L multi-level platform has four independent platforms, two on each side of the machine, than can hydraulically adjust sideways allowing the laborer to get closer to the tree. The two lower platforms can manually adjust vertically with the two higher platforms at the back able to hydraulically adjust vertically allowing laborers to reach the top of the tree. The Zucal Z11 multi-level platform has two independent platforms, one on each side of the machine, that can hydraulically adjust sideways as well as up and down. These independent platforms has two levels each, i.e., the two laborers on each independent platform worked at different heights in the tree.

Productivity measurements

For trials where rows were used as replicates, productivity was measured by recording the time it took to prune or thin a row with a specific number of trees. This was converted into the number of trees pruned or thinned per laborer per hour, as well as manhours (MH) per ha (hours·ha^{-1}).

For trials where days were used as replicates, productivity was measured by converting the number of trees pruned or thinned on that day to the number of trees pruned or thinned per laborer per hour, as well as MH per ha (hours·ha^{-1}).

Trial-specific materials and methods

Trial 1: The trial was performed in a 22-year-old 'Flavour Top' nectarine orchard. Pruning took place on 29, 30 January, 22, 25 to 28 February and 1 to 3 March 2013. The team on the Hermes multi-level platform consisted of six pruners, one on each of the independent platforms, two on the ground in front of the machine and an operator. The laborers used pneumatic pruning shears to remove strong upright shoots and branches competing with the leaders. Hacksaws were used to remove dead- and non-bearing wood or branches that caused excessive overshadowing. The laborers in the conventional team had the same instructions but had to use hand pruning shears and hacksaws.

Trial 2: The trial was performed in a 13-year-old 'Abate Fetel' pear orchard. Pruning took place on 23, 26, 27, 30 August and 2 September 2013. The team on the Hermes multi-level platform consisted of six pruners, one on each of the independent platforms, two on the ground in front of the machine and an operator. The laborers on the platform as well as in the conventional team used hand pruning shears to cut two-year-old shoots back to two or three reproductive buds, thin weak spurs to one reproductive bud and cut away strong upright shoots while leaving medium sized one-year-old shoots to develop reproductive buds.

Trial 3: The trial was performed in a 14-year-old 'Cripps' Pink' apple orchard. Pruning took place on 1 August, 4 to 6, 12 to 14, 26, 27 September and 1 October 2012. The team on the Hermes multi-level platform consisted of six pruners, one on each of the independent platforms, two on the ground in front of the machine and an operator. The laborers used pneumatic pruning shears to cut away strong upright shoots and to singulate the tips of bearing branches. The laborers in the conventional team had the same instructions but had to use hand pruning shears.

Trial 4: The trial was done in a 14-year-old 'Royal Gala' apple orchard. Pruning took place on 3 and 4 September 2013. The team on the Hermes multi-level platform consisted of six pruners, one on each of the independent platforms, two on the ground in front of the machine and an operator. The laborers on the platform as well as in the conventional team used hand pruning shears to remove strong upright shoots, remove upright branches competing with the leaders, remove forks on branches and to thin spurs by spacing them a shear length apart on a bearing branch. Hacksaws were used to remove bearing branches that caused excessive overshadowing and reached too far into the row. Younger shoots were tied down into gaps where bearing branches were removed.

Trial 5: The trial was done in a 5-year-old 'Pacific Gala' apple orchard. Pruning took place on 16, 17, 22, 24 to 26, 29 to 31 July, 1, 2, 5 and 6 August 2013. The team on the Zucal multi-level platform consisted of six pruners, two on the net platform, one on each of the independent platforms, and two on the ground in front of the machine. One of the pruners on the net platform was the operator. The laborers used pneumatic pruning shears to remove bearing branches that were too close to one another, cut weak shoots on the bearing branch back to a reproductive bud, remove all growth on the abaxial sides of a bearing branches and cut away all spurs and weak shoots within a shear length from the trunk. The laborers in the conventional team had the same instructions but had to use hand pruning shears.

Trial 6 and 7: These trials were done in a 11-year-old 'Royal Gala' and 11-year old 'Fuji' apple orchards, respectively. Thinning took place on 26 to 28 and 27 to 29 November 2013, respectively. Rows had to be used as replicates because the orchard, due to its small size, would not provide enough days of thinning to use days as replicates. The team on the Zucal multi-level platform consisted of eight thinners, two on the additional hail net platform, one on each of the independent platforms, two on the ground in front of the machine and an operator. The laborers on the platform as well as in the conventional team thinned heavily bearing branches to one fruit per cluster and lighter bearing branches to two fruit per cluster. The number of faults per tree was counted at three sections within each row, with each section consisting of nine consecutive trees. Each cluster of fruit left unthinned as well as branches that were not thinned according to instructions were counted as faults.

Statistical analysis

Data were subjected to one way Analysis of Variance (ANOVA) by General Linear Methods using SAS Enterprise guide version 5.1 (SAS Institute Inc. Cary, North Carolina, United States of America). Means that differed significantly at $p \leq 0.05$ were separated by the Least Significant Difference (LSD). A single degree of freedom, orthogonal contrast was fitted for conventional vs. platform pruning in Trial 1.

Results

Results for trials 1 to 7 are provided per trial in Tables 5 to 11. Percentage increase or decrease referred to below were calculated from the hours·ha^{-1} unit.

Summer pruning

In trial 1, laborer productivity on the platform was significantly higher (339 to 431%) compared to conventional teams when summer pruning ‘Flavour Top’ nectarine trees (Table 5). Trial 1 also showed that the pneumatic pruning shears did not significantly increase labor productivity on the platform compared to the same laborers with hand shears.

Dormant pruning

In trial 2 the laborers on the platform were significantly more productive (112%) performing dormant pruning on ‘Abate Fetel’ pear trees compared to the conventional team (Table 6). In trials 3 (Çripps’ Pink) and 4 (‘Royal Gala’) there were no significant differences between platforms and conventional teams in terms of laborer productivity (Tables 7 and 8). Trial 3 showed an increase in productivity for the laborers on the platform of 26%, whereas in trial 4 a 25% decrease in productivity was seen for the laborers on the platform. In trial 5 on ‘Pacific Gala’ the use of the platform significantly increased the productivity of laborers by 25% (Table 9).

Fruit thinning

Both fruit thinning trials showed an increase in productivity by the laborers on the platform compared to the conventional team (Table 10 – 11), with a significant increase (43%) in trial 6 on ‘Royal Gala’ (Table 10). Both trials also showed an increase in the number of mistakes made per tree, with the team on the platform (2.1 faults per tree) making significantly more mistakes than the conventional team (1.0 mistake per tree) in trial 7.

Discussion

Platform and orchard-related factors that influence productivity and efficiency

In the 'Royal Gala' and 'Pacific Gala' pruning trials (Trial 4 and 5), scaffold branches of the trees grew 1.0 – 1.8 m into the row. This forced the machine to stop to allow the individual platforms to be shifted out far enough for the pruners to reach the inside of the tree, do the pruning and retract the platforms before the machine could move forward. Overall team productivity was decreased due to this inefficiency, because the laborers were forced to work together as a team. One laborer pruning more slowly or having more pruning to complete, held back the entire team because they had to wait for him/her to finish and retract the platform before the machine could move forward. However, in trial 5 the team on the platform still managed a higher productivity compared to the conventional team whereas the team in trial 4 did not. This difference might be due to the orchard in trial 5 being younger than the orchard in trial 4; hence the scaffold branches in trial 5 were thinner and could bend out of the way with the passing of the machine. This allowed the machine to move forward without the need for laborers to maneuver scaffold branches out of the way. The scaffold branches in trial 4 were more rigid and interrupted machine movement. We observed in a summer pruning trial on apples (data not shown) that the chainsaws fitted on extension poles (1.5 – 2.5 m) allowed the laborers to reach the interior of the tree without having to shift out the individual platforms. This allowed unhindered machine movement thereby increasing productivity. Pneumatic pruning shears can also be fitted to such poles and may increase productivity for certain orchard tasks in orchards with less than ideal tree structures. The same effect can be achieved when replacing hand pruning shears with loppers. However the use of such equipment require physically strong laborers to do the task. Another concern in orchards where scaffold branches extend far into the work row is the damage the platforms may inflict on the trees in breaking these branches and breaking-off spurs as the branches scrape along the side of the platform (Figure 1-5). In the case of the 'Pacific Gala' trial (Trial 5), the team on the platform managed to increase their productivity by 31%, but whether it offset the damage done to the trees is uncertain. It is likely that less damage would be incurred with platform use in the same orchard in the next season, because branches damaged during the previous season would have been cut away. This type of adaptation may cause a slight decrease in yield as was seen in the orchard adaptation trial in Paper 1.

We observed during trial 4 that when using a platform to manipulate trees with long scaffold branches such as the vertical axis training system, laborers sometimes had difficulty executing the instructed task. Often when the laborers bent down younger shoots in the place of removed scaffold branches, the platform itself was in the way and laborers were forced to tie down these shoots in less than ideal positions. Shoots that were supposed to be tied horizontally along the row direction were tied at various angles and often not into gaps. This might cause shading problems in future.

The configuration of multilevel platforms caused laborers to be idle when entering or exiting a row as discussed in Paper 1. The laborers on the lower levels and on the ground in front of the platform first had to prune or thin the lower part of the trees before the machine could move forward to allow the laborers on the machine to start pruning or thinning. When exiting a row, the reverse happened. This was more of a problem when pneumatic shears were used and laborers on the ground had to stay with the platform. When using hand pruning shears, laborers on the ground could work at their own rate. When doing pruning with hand shears and also when hand thinning, it is advisable that the laborers on the ground operate in their own team independent from the laborers on the platform. This will encourage better productivity of the laborers in both teams. The laborers on the ground could still be individually motivated to maximize productivity while the laborers on the platform could now operate in a smaller team thereby minimizing the effect of idle workers on overall team productivity.

The highest level most platforms can reach is a height of around 2.5 m (Table 4), limiting the maximum comfortable working height to around 3.5 m. We observed that too high trees induced inefficiencies on the machines since the pruners on the highest level had to prune almost half of the tree while the laborers on the lower level and on the ground were idle. When working in orchards with tall trees, care should be taken to avoid an unpruned or –thinned gap between the laborers on different platform levels. In trials where single level platforms were used (Data not shown), trees were divided into only two sections. The unthinned or -pruned gap arose in the middle of the tree where the laborer on the ground had to stretch while the laborer on the platform had to bend down very low and both could not quite reach the fruit or branches. Using multilevel platforms and then dividing the trees into smaller, easier to reach and slightly overlapping sections should easily address this problem.

Trial 7 showed a decrease in thinning quality for the laborers on the platform without any difference in thinning productivity. An observation made in this trial and comments from the laborers on the platform suggest that the decrease in the effectiveness of thinning on the platform might be due to the fact that laborers are stationary on a single level and this may cause certain fruitlets to be obscured from the view of the laborer on the platform, especially in a more dense canopy. In contrast, the laborers in the conventional team constantly change their viewing angle and therefore may have a greater chance to see all the fruitlets.

Trees with narrow canopies, as were seen in trial 2, 6 and 7, allowed the machine to continuously move forward with the driver just having to adjust the speed to allow laborers adequate time to do the work properly. However, the fact that the increase in productivity in trial 7 was not significant, suggests that a narrow tree canopy will by itself not always guarantee a substantial increase in productivity. Other factors such as crop load, the laborer team and management will also determine the end result when a laborer platform is used in a suitable orchard (K. Lewis, Personal communication). Lehnert (2013) argues that there is more to gain from adapting tree architecture to narrower, taller trees than just laborer productivity. A narrower tree improves light distribution within the canopy and when managed correctly can be high yielding with improved fruit quality and more efficient application of pesticides.

To reap the full benefit from the use of laborer platforms, producers should aim to adopt dormant pruning strategies which require less and simpler pruning. This will make dormant pruning similar to summer pruning in the sense that the ladder is moved a lot for little pruning per tree (Sazo and Robinson, 2013). This resonates with a statement made by Lehnert (2013) that simpler tasks can be performed quicker with the use of a platform and therefore producers should aim to adopt simpler orchard management practices. Along the same lines, Robinson (2011) and Robinson et al. (2013) argue that future development of robotics for pruning of apple trees will benefit from a simple training system, with a pruning strategy simplified to one rule, e.g. prune away branches more than 2 cm in diameter. However, Robinson et al. (2013) express doubts about whether such technology will be affordable and efficient enough to decrease pruning cost compared to conventional pruning. Nonetheless, it seems that producers should strive toward simpler and easier to maintain training systems.

Labor-related factors that influence productivity and efficiency

Monitoring the quality of pruning and thinning is much harder than compared to harvesting. When pruning and thinning, the laborer has to rely on his/her own judgment to make decisions about what and where to cut and thin. This leaves room for the laborer's own interpretation of what needs to be done (Lehnert, 2013). The decision/opinion of the laborer may differ from that of the crew boss and manager, thus it is hard to explicitly quantify the quality of job done. On the other hand, with picking, especially with strip picking, it is easier to monitor the quality of the job done because the instructions are simple and the results are more visible. It is for this reason that the machine operator and crew boss play such an important role on the laborer platform when it comes to tasks such as pruning and thinning. They determine the speed of the machine and by doing so also the quality of the job as was seen in trial 2 where detailed pruning was conducted. According to the production manager on the farm, too fast a machine speed set by the operator led to a decrease in the quality of the pruning because laborers skipped the parts of the tree they could not reach or finish in time. Thus an increase in productivity was seen in trial 2 but with a concomitant decrease in efficiency.

The piece rate motivation of laborers can potentially create a situation where they are indirectly incentivized to cut corners as long as they are not caught. This may lead to unsatisfactory work quality of as well as friction between producer, crew boss and laborer. Producers should aim to incentivize laborers to take inherent responsibility for correct job execution. If producers could find a way to reward both productivity and quality of the job, laborers might be motivated to do a proper job at a decent rate thereby proving more efficient. Furthermore, the team structure should allow for conflict resolution and laborer complaints to take place in order to avoid friction between laborers, managers and producers (Sazo et al., 2010). The laborers working on the platforms in this study suggested that allowing them to pick their own teams may prevent friction within the team. Elkins et al. (2010) also found that productivity increased when laborers were allowed to pick their own teams.

As laborers gain experience on the platforms, incremental increases in productivity may be seen. The increasing trend in productivity outputs per replication seen in trial 5 supports this notion (Figure 6). It is difficult to foresee what the eventual productivity levels will be. According to the production manager on the farm such increases will not come about effortlessly and will require consistent training and motivation of the laborers to reach their full potential on these machines.

General remarks

The pneumatic pruning shears were found to be too big and heavy for the fast and precise maneuvering required to make detailed pruning cuts in trial 2. Hence, hand pruning shears were used instead. When working with pneumatic pruning tools, laborers must maintain a high level of concentration. The pneumatic shears and the pipes that connect them to the compressor are potential hazards if laborers handle the equipment carelessly. The pneumatic pruning equipment needed routine maintenance and adjustment for proper functioning. Laborers should therefore be trained to make these adjustments in the field in order to prolong the useful life of the equipment. In cases similar to trial 1 where a large increase in productivity is found, it is advisable to make use of pneumatic/electric pruning equipment because each individual laborer is making three to four times the number of cuts they would have made in a conventional team. Laborer may in the long run incur repetitive motion injuries when using hand pruning shears on platforms.

Although a dedicated operator or driver might be warranted in cases where the platform moves at a constant fast pace or where the terrain is rough, Warner (2013) reports that it is more cost-efficient if one of the laborers working on the platform acts as the operator as well. Producers should consider this when buying or building a platform because not all platforms can be operated by a laborer on the platform that also prunes or thins. Machines that are functional, simple and durable will be the more sensible options (Warner, 2013). Simple, durable machines will translate into less downtime for repairs and maintenance.

Conclusion

The efficacy of platforms on overall farm productivity may differ from farm to farm. As discussed in (Paper 1), productivity gains will mainly depend on the current productivity and efficiency levels of the farm. The solution that works on one farm will not necessarily be transferable to other farms. E.g., some producers might opt to not use platforms because it does not fit in with their precision farming pruning and thinning practices (Warner, 2014). Some producers will opt to adapt tree architecture and training systems to optimize the use of platforms for certain orchard tasks. Other producers may use platforms to enable laborers to perform orchard tasks they were previously unable to do, e.g. older laborers who had trouble carrying around ladders.

Although significant increases in productivity were seen in most of the trials in this study, it is important to keep in mind that most of these trials were conducted in orchards that allowed easy access to the platforms. 61% of apple orchards, 56% of pear orchards, 25% of peach orchards and 16% of nectarine orchards in the South African deciduous fruit industry are older than 16 years (HORTGRO, 2013). Although these numbers do not necessarily relate to the exact percentage of suitable and unsuitable orchards in the industry, it does give an idea of the current situation in the South African deciduous fruit industry. Older orchards were typically planted at lower density to larger, more complex trees with bigger canopies and a more rigid structure often extending into the work row. The importance of this lies in the fact that on many deciduous fruit farms a large proportion of orchards prohibits the use of laborer platforms because of the misalignment between tree architecture and machine design, especially on pome fruit farms. Trial 4 and 5 were examples of such orchards that were not particularly suitable for mechanization. The platforms caused damage to trees in these orchards, which in trial 4 resulted in a decrease in productivity. It seems that the larger percentage of younger orchards in the stone fruit industry might facilitate the faster adaptation of laborer platforms, with the proviso that the basic tree structures are suitable. The use of laborer platforms in pome fruit orchards may gradually increase as training systems are adapted with the establishment of new orchards to the more efficient two-dimensional structures as is the international trend.

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Table 1: Specific orchard detail provided per trial.

Trial	Fruit kind	Cultivar	Year planted	Age	Row orientation	Aspect
1	Nectarine	Flavour Top	1991	22	North-South	Flat
2	Pear	Abate Fetel	2000	13	East-West	West
3	Apple	Cripps' Pink	1999	14	North-South	North
4	Apple	Royal Gala	1999	14	East-West	West
5	Apple	Pacific Gala	2008	5	North-South	South
6	Apple	Royal Gala	2002	11	North-South	Flat
7	Apple	Fuji	2002	11	North-South	Flat

Table 2: Specific orchard detail provided per trial.

Trial	Cultivar	Row width (m)	In row (m)	Trees·ha^{-1}	Training system	Tree height	Tree width
1	Flavour Top	4.0	1.5	1667	Central leader	3.5 – 3.6	1.4 – 1.8
2	Abate Fetel	4.0	1.5	1667	Central leader	3.6 – 4.0	1.6 – 2.0
3	Cripps' Pink	4.0	1.5	1667	Central leader	2.7 – 3.2	1.2 – 2.2
4	Royal Gala	4.5	2.0	1111	Solaxe	3.5 – 3.9	2.0 – 3.6
5	Pacific Gala	4.0	1.75	1429	Solaxe	3.8 – 4.0	2.4 – 2.8
6	Royal Gala	3.5	0.75	3810	Central leader	3.5 – 3.8	1.2 – 1.8
7	Fuji	3.5	0.75	3810	Central leader	3.5 – 3.8	1.2 – 1.8

Table 3: Specific harvest detail provided per trial.

				Replications		
Trial	Cultivar	Action	Monetary Incentive[z]	Platform	Conventional	Type
1	Flavour Top	Summer prune	Piece	10	2	Days
2	Abate Fetel	Dormant prune	Day	3	5	Rows
3	Cripps' Pink	Dormant prune	Piece	8	3	Days
4	Royal Gala	Dormant prune	Day	3	3	Rows
5	Pacific Gala	Dormant prune	Piece	12	13	Days
6	Royal Gala	Fruit thin	Day	5	5	Rows
7	Fuji	Fruit thin	Day	6	3	Rows

[z]Piece rate refers to pickers being paid a fixed price per harvested bin and day rate refers to pickers being paid a fixed price per day.

Table 4: Physical dimensions of harvesting systems and platforms used in trials.

Dimension	N.Blosi	Hermes Tecno L	Zucal
Length (mm)	3000	4900	4200
Minimum width (mm)	1830	2070	1600
Maximum width (mm)	3850	3470	3000
Maximum height(mm)	2500	2875	2600

Table 5: Effect of pruning method on laborer productivity for summer pruning of 'Flavour Top' nectarines (Trial 1).

Treatment	Trees·hour^{-1}	Hours·ha^{-1}
Conventional	8 b[z]	202 a
Platform (Hand pruning shears)	45 a	38 b
Platform (Pneumatic pruning shears)	37 a	46 b
p values		
Treatment	0.0013	<0.0001
Conventional vs Platform	0.0004	<0.0001

[z] Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.

Table 6: Effect of pruning method on laborer productivity for dormant pruning of 'Abate Fetel' pears (Trial 2).

Treatment	Trees·hour^{-1}	Hours·ha^{-1}
Conventional	3 b[z]	587 a
Platform	6 a	277 b
p value	0.0028	0.0062

[z] Any two means within a row not followed by the same letter are significantly different at $P \leq 0.05$.

Table 7: Effect of pruning method on laborer productivity for dormant pruning of 'Cripps' Pink' apples (Trial 3).

Treatment	Trees·hour^{-1}	Hours·ha^{-1}
Conventional	18 ns	93 ns
Platform	23	74
p value	0.1489	0.1695

Table 8: Effect of pruning method on laborer productivity for dormant pruning of 'Royal Gala' apples (Trial 4).

Treatment	Trees·hour^{-1}	Hours·ha^{-1}
Conventional	5 ns	245 b[z]
Platform	4	306 a
p value	0.0602	0.0510

[z] Any two means within a row not followed by the same letter are significantly different at $P \leq 0.10$.

Table 9: Effect of pruning method on laborer productivity for dormant pruning of 'Pacific Gala' apples (Trial 5).

Treatment	Trees·hour^{-1}	Hours·ha^{-1}
Conventional	9 b[z]	166 a
Platform	12 a	131 b
p value	0.0075	0.0238

[z] Any two means within a row not followed by the same letter are significantly different at P ≤ 0.05.

Table 10: Effect of thinning method on laborer productivity and thinning quality for fruit thinning of 'Royal Gala' apples (Trial 6).

Treatment	Trees·hour^{-1}	Hours·ha^{-1}	Faults·tree^{-1}
Conventional	15 b [z]	265 a	0.39 ns
Platform	21 a	185 b	0.65
p value	0.0240	0.0485	0.3353

[z] Any two means within a row not followed by the same letter are significantly different at P ≤ 0.05.

Table 11: Effect of thinning method on laborer productivity and thinning quality for fruit thinning of 'Fuji' apples (Trial 7).

Treatment	Trees·hour^{-1}	Hours·ha^{-1}	Faults·tree^{-1}
Conventional	11 ns	357 ns	0.95 b [z]
Platform	13	308	2.12 a
p value	0.3983	0.3564	0.0288

[z] Any two means within a row not followed by the same letter are significantly different at P ≤ 0.05.

Figure 1: Damage caused by laborer platform on 'Royal Gala' apple trees during dormant pruning (Trial 4).

Figure 2: Damage caused by laborer platform on 'Royal Gala' apple trees during dormant pruning (Trial 4).

Figure 3: Damage caused by laborer platform on 'Royal Gala' apple trees during dormant pruning (Trial 4).

Figure 4: Damage caused by laborer platform on 'Pacific Gala' apple trees during dormant pruning (Trial 5).

Figure 5: Damage caused by laborer platform on ‘Pacific Gala’ apple trees during dormant pruning (Trial 5).

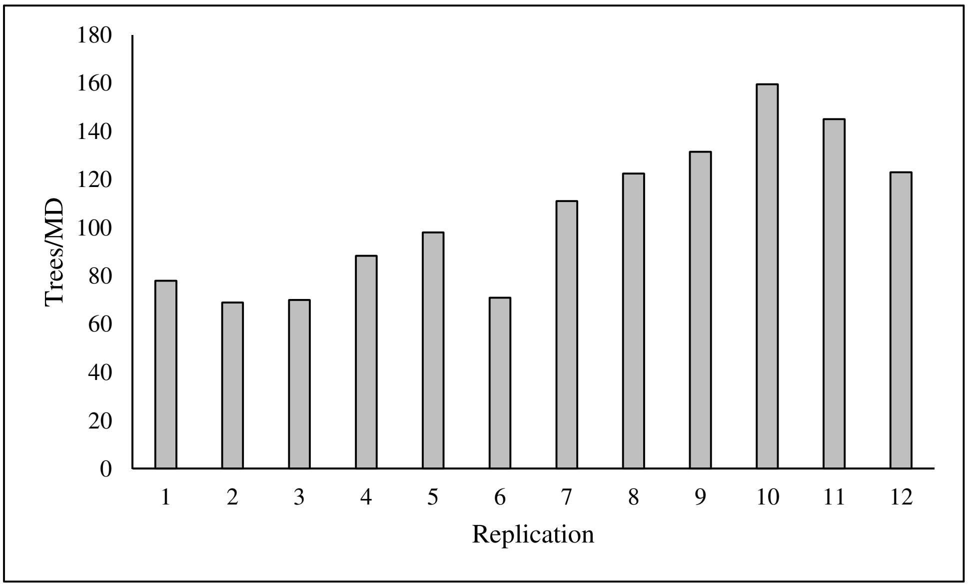

Figure 5: Individual replication Trees/MD outputs of the laborer platform for dormant pruning of ‘Pacific Gala’ apples (Trial 5)

PAPER 4: MODELING THE COST EFFECTIVENESS OF PLATFORMS ON LABOR AND PRODUCTION COSTS IN SOUTH AFRICAN DECIDUOUS FRUIT ORCHARDS

Abstract

Additional index words. Mechanization, labor productivity, orchard action costs

A deterministic model was developed to compare the costs of orchard actions when performed by conventional labor, laborers on platforms and a combination of conventional practices and platforms. Productivity levels used in the analysis were based on the findings of field research conducted with harvesting systems and laborer platforms. The analysis aimed to demonstrate the working of the model and the analysis was applied to a typical South African pome fruit farm. The analysis showed that the orchard actions performed, purchase price of the laborer platform, method of propulsion, labor productivity, -cost and –structure all impact on the feasibility of investing in laborer platforms. There seems to be little justification toward the complete replacement of ladders on deciduous fruit farms on pure economic basis, seeing that this will require a large capital investment. The more viable approach seems to be to partially mechanize certain orchard tasks with an affordable, durable and simple to operate laborer platform.

Introduction

Options to mechanize fresh market deciduous fruit production are limited when compared to mechanization options in field crop and vegetable production. The major difference between these farming systems is that most of the machinery deciduous fruit farmers employ aim to increase the efficiency of the laborers (Robinson, 2011) rather than substitute laborers completely as was seen with the advent of combine harvesters as described in Van Zyl et al. (1987). Furthermore, field crop farmers have a wide range of machinery to choose from for various tasks that needs to be performed on the farm whereas on deciduous fruit farms, laborer platforms can be used for any orchard activity that requires the use of ladders. It is this attribute and the variability in human productivity that creates some unique challenges when developing a cost model for a deciduous fruit farm.

Evaluation of economic models

The concepts used in machinery selection models developed for field crops by Camarena et al. (2004), Lazzari and Mazzetto (1996) and Aderoba (1987), give insight as to what factors to consider when developing machinery selection models for the deciduous fruit industry. Aderoba (1987) developed a model for selective mechanization of field crops for small farmers that allows producers to decide on the most affordable way of partially mechanizing their farming operations. Aderoba (1987) opted for a selective mechanization approach because of the difficulties small farmers experience with regard to full scale mechanization. A selective mechanization approach toward fruit production makes sense because the technology currently available for full scale mechanization is expensive, not yet proven and not necessarily interchangeable between different countries and production systems (Sarig, 2005). Accordingly the model discussed in this paper was designed to allow the user to choose which orchard actions to include in the analysis.

Camarena et al. (2004) suggest that smaller farmers consider a joint ownership approach when buying expensive machinery. This approach is commonly seen in European fruit producing regions where production units are relatively small (3 to 17 ha) (K. Martini, personal communication) and individual farmers will not be able to justify the capital investment on their own. Joint ownership of machinery is a less viable option in countries with larger production units such as South Africa. The same concept could, however, be applied to large corporations with multiple production units in various production areas that could benefit from economies of size when investing in expensive agricultural machinery. The laborer platforms can then be used for orchard actions where larger productivity gains are achieved (e.g. summer pruning) for larger parts of the year, making the laborer platform more cost efficient as a whole.

The cost analysis model discussed in this paper forms part of a research project initiated by HORTGRO Science to evaluate the use of harvesting systems and laborer platforms under South African conditions. The effect of harvesting systems on harvesting related fruit damage was also investigated. Harvesting systems did not significantly decrease harvest related fruit damage and therefore did not have a direct impact on the quality of the harvested fruit (Paper 2). Consequently, it will not influence the prices received for fruit compared to conventional harvesting. It is for this reason that the economic analysis in the model discussed in this paper consists only of a cost analysis. The research showed that for certain orchard tasks in appropriate orchards, platforms have the potential to increase labor productivity (Paper 3) but not necessarily for harvesting (Paper 1). This model focusses on comparing the costs involved when performing various orchard tasks either by conventional labor teams, laborers on platforms as well as a combination of conventional and platform teams. The model makes provision for the following orchard actions: trellis construction, tree training, summer pruning, dormant pruning, flower thinning, fruit thinning and harvesting.

Producers want economic models to be very adaptable in order to be used for specific situations on specific farms. Therefore models should be user friendly and allow changes in any variable to allow sensitivity analysis with regard to critical parameters (Camarena et al., 2004; Lazzari and Mazzetto, 1996). This cost analysis model strive to do that in the sense that orchard actions, costs, productivity levels, orchard size, allocation of workdays and monetary incentive can all be specified by the user.

Parameter specification for analysis

The analysis discussed in this section serves only as an example of how the model can be used. The purpose of developing the model was to provide producers with a decision making tool with which they can assess the impact of laborer platforms and changes in labor structure on labor and production costs. In order to fully utilize the model, producers will have to specify the model parameters applicable to their own farming situation and then do sensitivity analyses with regard to changes in costs, productivity and labor structure. The orchard actions, trellis construction, tree manipulation, summer pruning, dormant pruning and fruit thinning were included in this analysis. Harvesting was omitted because our trials did not show any significant increases in productivity for harvesting of pome fruit with harvesting systems and laborer platforms (Paper 1). Furthermore, on many farms the implementation of harvesting systems and laborer platforms for harvesting will require additional capital expenditure and operational rearrangements in order to accommodate these machines (Paper 1).

The model calculates the labor-, diesel-, maintenance- and depreciation costs for each action with interest and insurance costs being calculated as a yearly fixed cost. Table 1 shows the formulas and assumptions for calculating various machinery cost items used in this analysis (Based on Lubbe and

Archer (2013)). For the combination analysis, only one laborer platform was specified. The assumed lifetime of the laborer platform was 40 000 hours and for an aluminum ladder it was 5 000 hours. The laborer platform price is set at R200 000 with the price of an aluminum ladder being R1 100.

The farm used in the analysis had the fruit kind and cultivar composition of a typical pome fruit farm of 55 ha, as described by Meyer et al. (2012). Each year approximately 5% of the planted orchards are reestablished, amounting to around 3 ha of orchard being planted every year, making for an orchard replacement cycle of approximately 20 years. Tree density is fixed at 1 667 trees·ha^{-1}, i.e. 4.0 m × 1.5 m tree spacing. Diesel price per liter was assumed to be R11.55 as indicated on 5 November 2014 (Automobile Association, 2014). It was assumed that laborers were paid day rate for all activities - see Table 2 for daily wage for each labor category. For the purpose of the analysis, in all orchard actions except for trellis construction, the conventional teams consisted of 16 general laborers with one crew boss per team and platform teams consisted of six general laborers and one driver per team. The teams used for the trellis construction consisted of two general laborers for conventional and platform teams with the platform team also having a driver. During the trials it was noticed that variation in workload distribution found in typical South African orchards necessitate a driver on the platform who can adjust the speed as the platform moves as well as to take the role of the crew boss in maintaining a high standard of work done (Paper 3).

A total of 200 working days were allocated with a workday consisting of nine working hours. The number of hectares, productivity levels and allocated workdays per action used in the analysis are provided in Table 3. The productivity levels used in the analysis were derived from the levels of productivity observed in trials where the use of laborer platforms managed to increase laborer productivity. The assumption was made that all the orchards on the farm were suitable for the use of a laborer platform. It is important to keep in mind that in their current state, a large proportion of orchards on deciduous fruit farms preclude the use of laborer platforms because of the misalignment between tree architecture and machine design, especially on pome fruit farms (Paper 3). Thus the farm used in the analysis resembles a farm with more desirable orchard architecture than the current average South African deciduous fruit farm.

The costs associated with each action at each of the productivity levels were calculated for three scenarios. The first being a farm where only conventional teams are used to perform the tasks, one where only platform teams are used and one where a combination of conventional and platform teams are used. For the scenario where only conventional teams or platform teams are used, the number of teams, laborers and machines needed to complete an action in the specified amount of time is calculated. For the combination analysis, the number of laborer platforms to be used in the analysis is specified by the user and preference is then given to the laborer platforms in the sense that work is always allocated to the laborer platforms first. The work that exceeds the capacity of the teams on the platforms is allocated to conventional teams. The number of conventional teams and laborers needed to complete the action in the required timeframe is then calculated.

The Net Present Value (NPV) capital budgeting technique was used in these analyses in order to determine whether the cost savings generated from the use of a laborer platform will justify the capital investment needed to purchase the laborer platform in certain scenarios. The NPV is the sum of the present values of all annual net cash flows less the initial investment plus the salvage value at the end of the planning period (Boehlje, 1984). If the NPV is a positive value, the investment is acceptable and if the NPV is negative, the opposite is true. The Annualized Net Present Value (ANPV) technique was calculated for all scenarios and was used to compare scenarios where the platform lifetimes were not equal (Boehlje, 1984). The ANPV is derived from the NPV with the following formula:

$$ANPV = NPV \times \frac{i(1+i)^n}{[(1+i)^n - 1]}$$

The ANPV formula converts the NPV into an equivalent annual amount that can then be compared to the ANPV's of other scenarios regardless of the lifetime of the platforms being compared. The scenario with the largest ANPV is the more economically favorable one.

Sensitivity analysis

The parameters as described above served as the baseline for comparison. With this choice of parameters, labor cost per hectare is reduced in all activities when performed with a laborer platform, thus reducing labor demand, but only tree manipulation (high productivity) and summer pruning (high and low productivity) showed decreases in total cost per hectare when comparing platforms and a combinational setup with conventional practice (Table 4). Similar tables to Table 4 can be constructed for all possible scenarios run with the model. The baseline NPV and ANPV for platforms and the combinational setup compared to conventional practice are displayed in Table 5 to 9. With the base parameters, the platforms operation will require a maximum of four laborer platforms and 24 general laborers, the conventional setup will require a maximum of two laborer teams with 32 general laborers and the combinational operation will require one laborer platform with six general laborers and two conventional teams with 32 general laborers.

Selection of orchard actions

Table 5 shows that if the laborer platforms are only used for orchard actions where total cost is reduced, the lifetime of the platforms are prolonged and that for both platforms and the combinational operation, a positive cost difference is obtained. This is even though ANPV for platforms increased, but remained negative, whereas for the combinational operation, ANPV increased by almost R10 000. If this approach is taken, it means that on a smaller farm the laborer platform will only be used for short periods throughout the year because summer pruning and tree manipulation are only done on certain times and in certain orchards. On a larger farm, this approach could however lead to bigger cost savings because these farms will typically have more hectares that needs to managed, meaning more time for the platform to be used where it saves the most money.

The impact of platform price

It seemed that the break-even platform price for a combinational operation is ≈ R300 000 because at this price NPV is decreased to R32 476.95 (Table 6). This indicates a favorable investment but leaves very little room for variation in productivity and other costs. At this price, NPV for the use of only platforms became more negative. When the platform price is decreased to R100 000, NPV for the combinational operation increased by ≈R160 000. For the platforms vs. conventional practice comparison, NPV turns positive but the combinational operations remains the more favorable investment seeing that its ANPV is much larger than the platform operation.

The impact of labor cost

The base minimum wage was set at R112 per day, which is compared to an R150 and a R200 per day minimum wage (Table 7). For both the R150 and the R200 scenarios, the annual cost difference between platforms and conventional practice turned positive, but NPV only turned positive when minimum wage was set at R200. However, the ANPV of the combinational operation was higher than the ANPV for the use of only platforms. This means that even at a minimum wage scenario of R200 per day the complete replacement of ladders with platforms will not be as cost effective as partially replacing ladders with a platform.

The impact of platform labor team structure

In Table 8 a comparison is made between the baseline scenario and a scenario where the driver on the platform is removed. This led to a doubling in annual cost difference for the combinational operation vs. conventional practice. It also turned the cost difference and NPV for the platforms vs. conventional practice scenario positive. However, the ANPV of the combinational operation was still larger than the ANPV for the use of only platforms, indicating once again that the partial replacement of ladders is preferred above a complete replacement. This serves as an indication of the overhead costs incurred when having laborers in teams who do not productively contribute to the work being done. In many cases these laborers are warranted for other reasons, but producers should be weary of when and where to include these laborers in teams.

The impact of laborer productivity

In appropriate orchards, laborer platforms should be able to consistently maintain productivity increases of 30% (K. Lewis, Personal communication). Thus a scenario was included in the analysis where platform laborer productivity for all orchard actions was increased by 30% over the baseline conventional team productivities. Table 9 shows that for this scenario both the platforms and the combinational operations the cost difference and NPV turns negative whereas with a 100% increase in productivity of platform laborers over conventional labor, both the platform and the combinational operations are viable investment opportunities. In this case, the use of only platforms has the largest ANPV, which makes it the most favorable investment. However it is unlikely that a constant 100% increase in productivity will ever be achieved in reality.

Diesel powered platform (Base) vs. electric powered platform

The cost of electricity for the electric powered platform was fixed at R1.00 per hour of use (T. Babl, Personal communication). Table 10 shows that the cost difference for the electric platform for both the platform and the combinational operations are positive but that the NPV for the platforms operation is negative. The combinational operation showed large increases in annual cost difference as well as NPV when using an electric powered platform instead of a diesel powered platform.

Conclusion

The cost analyses shown in this paper are subject to the parameters specified in the model and should not be seen outside of the context thereof. From these analyses it seemed that the only case where a 55 ha pome fruit farm could completely convert to the use of laborer platforms is if a 100% increase in productivity in all orchard actions are achieved with the use of laborer platforms. Not even large increases in labor cost would justify the decision to replace all ladders with platforms on an economic basis. Furthermore, these analyses showed that a 55 ha pome fruit farm would benefit most from the use of a laborer platform in combination with conventional labor teams. The platform should preferably be electric powered, require no dedicated driver and should cost less than R200 000. This would also be true for larger farms that might potentially benefit more due to having more hectares to perform orchard actions with larger productivity gains. The platform employed should be affordable, durable, simple to maintain and simple to operate.

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Table 1: Parameters for the calculation of various machinery costs items.

Cost items	Percentages
Salvage value (% of purchase price)	10%
Average investment = (Purchase price + Salvage value) / 2	N/A
Depreciation cost per hour = (Purchase price - Salvage value) / Lifetime in hours	N/A
Insurance cost (% of average investment)	1.75%
Interest cost (% of average investment)	8.50%
Platform maintenance cost per hour (% of purchase price/lifetime in hours)	120.00%
Other maintenance cost per hour (% of purchase price/lifetime in hours)	50.00%

Source: Adapted from (Lubbe and Archer, 2013).

Table 2: Daily wage received per labor category.

Labor category	Daily wage
Crew boss	R 130.00
Driver	R 120.00
General laborer	R 111.72

Table 3: Summary of the number of hectares to be completed for each orchard activity at the specified productivity levels within the allocated number of working days on a 55 ha pome fruit farm.

Productivity level	Unit	Trellis construction		Tree manipulation		Summer pruning		Dormant pruning		Fruit thinning	
		Conv.	Platform	Conv.	Platform	Conv.	Platform	Conv.	Platform	Conv.	Platform
Low productivity (Mature orchards)	Hectares	N/A	N/A	20	20	15	15	31	31	31	31
	Trees/MD	N/A	N/A	60	80	80	330	40	50	50	60
	Workdays allocated	N/A	N/A	20	20	15	15	60	60	40	40
High productivity (Young orchards)	Hectares	3	3	12	12	15	15	21	21	21	21
	Trees/MD	300	600	150	350	120	400	80	120	60	80
	Workdays allocated	5	5	10	10	10	10	20	20	20	20

Table 4: Summarized model outputs for the baseline situation.

Orchard action	Cost component	Conventional practice	Platform	Combination	
				Conventional	Platform
Trellis construction	Labor	R 1 862.00	R 1 431.00	R 0.00	R 1 431.00
	Diesel	R 0.00	R 433.13	R 0.00	R 433.13
	Maintenance	R 16.50	R 225.00	R 0.00	R 225.00
	Depreciation	R 29.70	R 168.75	R 0.00	R 168.75
	Interest	R 6.00	R 286.75	R 0.00	R 198.45
	Insurance	R 0.00	R 59.04	R 0.00	R 40.86
	Total	R 1 914.20	R 2 603.66	R 2 497.18	
Tree manipulation	Labor	R 82 559.89	R 62 410.19	R 47 405.36	R 23 333.26
	Diesel	R 0.00	R 8 208.75	R 0.00	R 3 069.00
	Maintenance	R 682.00	R 4 264.29	R 391.60	R 1 594.29
	Depreciation	R 1 227.60	R 3 198.21	R 704.88	R 1 195.71
	Interest	R 247.94	R 5 434.60	R 243.64	R 1 406.13
	Insurance	R 0.00	R 1 118.89	R 0.00	R 289.50
	Total	R 84 717.43	R 84 634.93	R 79 633.36	
Summer pruning	Labor	R 62 419.27	R 18 211.29	R 998.71	R 17 881.99
	Diesel	R 0.00	R 2 395.31	R 0.00	R 2 352.00
	Maintenance	R 515.63	R 1 244.32	R 8.25	R 1 221.82
	Depreciation	R 928.13	R 933.24	R 14.85	R 916.36
	Interest	R 187.45	R 1 585.82	R 5.13	R 1 077.62
	Insurance	R 0.00	R 326.49	R 0.00	R 221.86
	Total	R 64 050.48	R 24 696.46	R 24 698.60	
Dormant pruning	Labor	R 207 231.98	R 174 529.00	R 131 729.63	R 63 225.60
	Diesel	R 0.00	R 22 955.63	R 0.00	R 8 316.00
	Maintenance	R 1 711.88	R 11 925.00	R 1 088.18	R 4 320.00
	Depreciation	R 3 081.38	R 8 943.75	R 1 958.72	R 3 240.00
	Interest	R 622.35	R 15 197.76	R 677.01	R 3 810.17
	Insurance	R 0.00	R 3 128.95	R 0.00	R 784.45
	Total	R 212 647.58	R 236 680.08	R 219 149.75	
Fruit thinning	Labor	R 180 614.00	R 171 053.06	R 130 563.44	R 47 419.20
	Diesel	R 0.00	R 22 498.44	R 0.00	R 6 237.00
	Maintenance	R 1 600.50	R 11 687.50	R 1 156.98	R 3 240.00
	Depreciation	R 2 880.90	R 8 765.63	R 2 082.56	R 2 430.00
	Interest	R 581.86	R 14 895.08	R 719.82	R 2 857.63
	Insurance	R 0.00	R 3 066.63	R 0.00	R 588.33
	Total	R 185 677.26	R 231 966.33	R 197 294.97	

Table 5: Platform lifetime in years, annual cost difference Net Present Value (NPV) and Annualized Net Present Value (ANPV) for platforms compared to conventional and a combinational setup compared to conventional practice showing the impact of orchard actions.

Scenario		Baseline	Only tree manipulation and summer pruning
Platforms vs. conv.	Years[z]	32	40
	Annual cost difference[y]	R (31 574.53)	R 4 012.51
	NPV[x]	R (579 464.04)	R (324 640.79)
	ANPV[w]	R (54 812.82)	R (28 692.40)
Combination vs. conv.	Years	22	40
	Annual cost difference	R 25 733.09	R 35 969.44
	NPV	R 192 254.54	R 321 182.58
	ANPV	R 19 598.22	R 28 386.76

[z]Lifetime of platform in years.

[y]Annual difference in costs.

[x]Net Present Value of annual cost savings incurred over platform lifetime.

[w]Annualized Net Present Value of cost savings.

Table 6: Platform lifetime in years, annual cost difference Net Present Value (NPV) and Annualized Net Present Value (ANPV) for platforms compared to conventional and a combinational setup compared to conventional practice showing the impact of platform price.

Scenario		Baseline price R 200 000.00	Platform price R 100 000.00	Platform price R 300 000.00
Platforms vs. conv.	Years[z]	32	32	32
	Annual cost difference[y]	R (31 574.53)	R 16 653.31	R (79 802.37)
	NPV[x]	R (579 464.04)	R 1 498.93	R (1 196 427.01
	ANPV[w]	R (54 812.82)	R 137.52	R (109 763.16)
Combination vs. conv.	Years	22	22	22
	Annual cost difference	R 25 733.09	R 40 646.56	R 10 819.62
	NPV	R 192 254.54	R 352 032.12	R 32 476.95
	ANPV	R 19 598.22	R 35 885.78	R3 310.67

[z]Lifetime of platform in years.

[y]Annual difference in costs.

[x]Net Present Value of annual cost savings incurred over platform lifetime.

[w]Annualized Net Present Value of cost savings.

Table 7: Platform lifetime in years, annual cost difference Net Present Value (NPV) and Annualized Net Present Value (ANPV) for platforms compared to conventional and a combinational setup compared to conventional practice showing the impact of labor cost.

Scenario		Baseline: Minimum wage R 111.72	Minimum wage R 150.00	Minimum wage R 200.00
Platforms vs. conv.	Years[z]	32	32	32
	Annual cost difference[y]	R (31 574.53)	R 6 639.60	R 55 061.84
	NPV[x]	R (579 464.04)	R (180 927.12)	R 346 879.09
	ANPV[w]	R (54 812.82)	R (16 598.70)	R 31 823.54
Combination vs. conv.	Years	22	22	22
	Annual cost difference	R 25 733.09	R 49 937.49	R 81 571.94
	NPV	R 192 254.54	R 429 694.76	R 740 022.29
	ANPV	R 19 598.22	R 43 802.62	R 75 437.08

[z]Lifetime of platform in years.

[y]Annual difference in costs.

[x]Net Present Value of annual cost savings incurred over platform lifetime.

[w]Annualized Net Present Value of cost savings.

Table 8: Platform lifetime in years, annual cost difference Net Present Value (NPV) and Annualized Net Present Value (ANPV) for platforms compared to conventional and a combinational setup compared to conventional practice showing the impact of labor structure.

Scenario		Baseline	Excluding driver on platform
Platforms vs. conv.	Years[z]	32	32
	Annual cost difference[y]	R (31 574.53)	R 33 639.04
	NPV[x]	R (579 464.04)	R 113 368.87
	ANPV[w]	R (54 812.82)	R 10 400.74
Combination vs. conv.	Years	22	22
	Annual cost difference	R 25 733.09	R 49 291.10
	NPV	R 192 254.54	R 423 353.79
	ANPV	R 19 598.22	R 43 156.23

[z]Lifetime of platform in years.

[y]Annual difference in costs.

[x]Net Present Value of annual cost savings incurred over platform lifetime.

[w]Annualized Net Present Value of cost savings.

Table 9: Platform lifetime in years, annual cost difference Net Present Value (NPV) and Annualized Net Present Value (ANPV) for platforms compared to conventional and a combinational setup compared to conventional practice showing the impact of labor productivity.

Scenario		Baseline	30% productivity increase over conventional	100% productivity increase over conventional
Platforms vs. conv.	Years[z]	32	30	34
	Annual cost difference[y]	R (31 574.53)	R (77 053.47)	R 137 557.68
	NPV[x]	R (579 464.04)	R (1 067 480.98)	R 1 293 867.48
	ANPV[w]	R (54 812.82)	R (99 329.72)	R 117 301.81
Combination vs. conv.	Years	22	22	22
	Annual cost difference	R 25 733.09	R (22 608.25)	R 76 638.96
	NPV	R 192 254.54	R (274 093.94)	R 684 788.66
	ANPV	R 19 598.22	R (27 940.84)	R69 806.62

[z]Lifetime of platform in years.

[y]Annual difference in costs.

[x]Net Present Value of annual cost savings incurred over platform lifetime.

[w]Annualized Net Present Value of cost savings.

Table 10: Platform lifetime in years, annual cost difference Net Present Value (NPV) and Annualized Net Present Value (ANPV) for platforms compared to conventional and a combinational setup compared to conventional practice for a diesel powered platform vs. an electric powered platform.

Scenario		Baseline: Diesel powered	Electric powered platform
Platforms vs. conv.	Years[z]	32	32
	Annual cost difference[y]	R (31 574.53)	R 20 025.71
	NPV[x]	R (579 464.04)	R (35 017.50)
	ANPV[w]	R (54 812.82)	R (3 212.59)
Combination vs. conv.	Years	22	22
	Annual cost difference	R 25 733.09	R 44 373.36
	NPV	R 192 254.54	R 375 111.82
	ANPV	R 19 598.22	R 38 238.50

[z]Lifetime of platform in years.

[y]Annual difference in costs.

[x]Net Present Value of annual cost savings incurred over platform lifetime.

[w]Annualized Net Present Value of cost savings.

GENERAL DISCUSSION AND CONCLUSION

Harvesting

Labor is in short supply and expensive in Europe and therefore the industries in Europe are at the forefront of employing harvesting systems and labor platforms. Many South African producers have recently and are still visiting the deciduous fruit industries in various European countries with the intention to learn from the European industries as to how South African producers can address their own escalating labor costs. On these tours producers came under the impression that conveyor-type harvesting systems can increase individual picker productivity to 350 $kg{\cdot}hour^{-1}{\cdot}picker^{-1}$. This is also the picking rate that platform and harvesting system manufacturers claim pickers can achieve on their machines (Meccanica Zucal, 2014). On paper it makes sense because the machines replace ladders in the orchard, which means that since laborers don't have to walk and climb ladders anymore. Hence, they should spend more time picking, thereby increasing productivity. However, industry differences between South Africa and Europe as well as obscured inefficiencies caused by labor team dynamics and a misalignment between orchard and machine design limited productivity gains and in some cases even decreased productivity in this study.

The following productivity outputs and calculations are for apple harvesting, but the concepts explained are the same for other fruit kinds. Commercial scale research done in South Tyrol, Italy (ITA) showed that on average a laborer on a platform or harvesting system can pick 221 $kg{\cdot}hour^{-1}$ with a range of183 to 266 $kg{\cdot}hour^{-1}$. According to a technical advisor in South Tyrol, the harvesting rates for a picker on a ladder, laborer platform or a conveyor type harvesting system are 130 to 150 $kg{\cdot}hour^{-1}$, 160 to 200 $kg{\cdot}hour^{-1}$ and 200 $kg{\cdot}hour^{-1}$, respectively(K. Martini, personal communication). According to a researcher (K. Lewis, personal communication) in Washington State, in the United States of America (USA), a conventional picker can harvest between 360 to 410 $kg{\cdot}hour^{-1}$. In the trials done in this study, South African conventional pickers picked anything from 83 to 261 $kg{\cdot}hour^{-1}$, with an estimated industry average around 110 to 130 $kg{\cdot}hour^{-1}$. In South Africa (SA), a picker on a platform or harvesting system picked format a rate between 81 to 169 $kg{\cdot}hour^{-1}$. The considerably slower rate in South Africa compared to Europe is due to the much greater suitability of the narrow, uniform canopies, i.e., "fruiting walls", employed throughout Europe for machine and platform harvesting. This means that the limiting tree architectural, non-uniformity and planting system issues identified in SA trials are unlikely to be present in USA and European orchards but still there was no discernable difference between conventional pickers and the ones on the machines. Newly developed laborer platforms and harvesting systems show more promise but all of them require uniform and narrow tree canopies (K. Lewis, Personal communication).

Table 1 shows the effect of fruit size on harvesting productivity outputs for apples, using industry averages for conventional picking rates and fruit mass obtained from technical advisors and researchers from the various industries. The USA has the largest fruit, highest actual harvest rate and the highest constant picking rate in fruit·min^{-1}. The constant picking rate is calculated as follows and includes time for walking to and from the bin, emptying harvesting bags, climbing up and down ladders and moving the ladder:

$$Constant\ picking\ rate\ in\ fruit\ per\ minute = \left(\frac{Actual\ kg \cdot hour - 1}{Fruit\ mass}\right) \div 60$$

SA pickers picking 150 g fruit at 27 fruit min^{-1} (similar to USA pickers) translate into an actual harvesting rate of 245 kg·hour^{-1} compared to 385 kg·hour^{-1} in Washington State with an average fruit size of 240 g. This shows that it is the larger fruit size in the USA that enables pickers to achieve their high actual harvesting rates. A picking cycle can be defined as the movement of one of the picker's hands from the moment the hand removes one fruit from the tree, puts the fruit in the harvesting bag and the hand is back on the next fruit to be picked (Peppelman et al., 2006). The amount of picking cycles a picker can make is limited. When a picker is making the maximum amount of picking cycles in a certain amount of time, the only way to increase the number of kg of fruit picked is to increase the size of the fruit, i.e. more weight is moved per picking cycle. The same concept applies to pickers on harvesting systems and laborer platforms. The higher actual harvesting rates of pickers on platforms and harvesting systems in the USA and ITA can in some cases solely be ascribed to the harvesting of larger fruit. However, Table 1 does show that the constant picking rate for ITA and SA pickers is half of what USA pickers are achieving. This indicates conventional pickers in ITA and SA spend much more time not picking than USA pickers. Further research and observation will be required to determine the cause of this difference in time spend picking. It does however show the potential increases in productivity that can be obtained without the use of machines and regardless of fruit size.

Conventional pickers in South Africa at some occasions during the study harvested fruit at the same rate as pickers in Italy on harvesting systems similar to the ones used in this study. Therefore it is important that producers compare the level of harvesting productivity on their farm relative to the productivity outputs achieved in this study as well as to industry averages when considering mechanization. Each producer needs to decide for himself whether he is going to strive to optimize the conventional harvesting practices already employed on the farm or whether he is going to attempt to increase productivity by investing in machinery. In some cases producers may implement harvesting systems and platforms for harvesting due to other non-economic reasons (Sarig, 2005). These include an enlargement of the laborer pool and increased laborer comfort and safety. Producers may also employ platforms on farms for other tasks such as pruning and training and may consider using them for harvesting as a bonus (D. Havenga, Personal communication).

Producers who harvest into lugs (small plastic crates) are likely to see large improvements in productivity or at least a reduction in labor needed when using laborer platforms for harvesting. Conventional harvesting in this instance is very inefficient, since it consists of laborers who are responsible for supplying pickers with empty lugs, laborers who must hold lugs for pickers on ladders to harvest into, laborers who are responsible for collecting full lugs and loading them onto a trailer and laborers who are responsible for picking. Laborer platforms replace the labor needed to carry, hold and collect lugs and therefore eliminates the inefficiencies caused by these processes. Similar productivity gains are likely to be seen when switching from lugs to bulk bins because using bulk bins eliminates the same inefficiencies as the laborer platforms. However, laborer platforms allow these increases in productivity on sensitive cultivars that cannot be harvested into bulk bins (T. Babl, Personal communication).

Operational setup at harvest

(Sarig, 2005) states that in order to truly optimize the fruit production process, producers have to find specific solutions for each orchard. An example of this is found in (Warner, 2014a) where a producer used a combination of bin trailer harvesting and bin on the ground harvesting on his farm. He found that in young orchards and cultivars that are selectively picked, low yields per harvest (25 to 30 ton·ha^{-1}) results in bins being placed far apart when using bin on the ground harvesting. This forces laborers to walk long distances to empty their bags. In contrast, with bin trailer harvesting, the distance walked is minimized due to the trailer with bins accompanying the pickers down the row. The same effect can be achieved by moving the individual bins down the row with a forklift for bin on the ground harvesting but this may be logistically challenging and additional handling of the bin might result in more fruit injuries.

At harvest time the logistics behind the efficient operation of platforms and harvesting systems can be disruptive to conventional practices employed on the farm. Most harvesting systems and platforms leave full bins on the ground, which necessitates a forklift of some sort to remove the bins from the orchard. Farms that employ bin on the ground harvesting already have the equipment to extract bins out of the orchard but the harvesting rate of the harvesting systems and platforms in this study will not productively employ a dedicated forklift and driver for one machine. Thus producers will either need multiple harvesting systems and platforms or will have to incorporate the harvesting system into a conventional bin on the ground team. Farms that do bin trailer harvesting are faced with larger challenges when using machine harvesting because there is no pre-existing means of transporting full bins out of the orchard. This will require the purchase of additional equipment to the harvesting system and platform. Here producers should consider all available options: Off-road forklifts, tractor-mounted forklifts or specialized bin trailers can be used to transport bins to and from the orchard. On one of the farms in this study, the full bins on the platform were off-loaded onto a trailer standing outside the orchard. The trailer was fitted with rollers on which full bins could slide. This eliminated the need for a forklift to pick bins up from the ground but it can be a time consuming process and pickers are idle while unloading bins. With some practice and if the trailer can be parked in the row in front or behind the platform, the process should be significantly sped up but will still have the disadvantage of the platform or harvesting system being dependent on the availability of a trailer in order to offload.

Pre-sorting facilities at pack houses will aid conventional harvesting as well as mechanically assisted harvesting by eliminating the need for in-orchard sorters. Conventional harvesting may benefit from the cost savings of not having sorters in the orchard as well as having more space for pickers to move around because there are less people in the orchard. It will also provide opportunity for individually motivated bin on the ground picking (i.e. one picker per bin), which was found by (Cuskaden, 1973) to improve individual picker productivity. Mechanically assisted harvesting may also benefit from the cost savings and more workspace of not having sorters in the orchard. Pre-sorters will also eliminate the need for a cull bin on the harvesting systems and platforms, which may decrease the cost of the machine.

Harvest injuries

The idea of harvesting systems decreasing harvesting injuries because there is less human handling of fruit makes sense in theory, but this study showed that in reality outcomes vary. Injury levels are generally low on hardier cultivars leaving little room for improvement whereas on sensitive cultivars there is much room for improvement because of high injury levels. Harvesting systems seemed to decrease harvesting injuries on hardier cultivars and obtained similar or higher levels of injury on the more sensitive cultivars. It was also interesting to note that in one of the trials on a sensitive cultivar, one conventional team obtained significantly lower levels of harvesting injuries than all other teams whether conventional or on machines. On further inquiry it was found that the particular team have consistently maintained low levels of harvesting injuries over the past seasons and take great pride in their performance (J. Visser, Personal communication). This indicates that harvesting injury levels are not related solely to the method of harvesting. Training, skill, motivation, incentive and monitoring of laborers may also play a role, regardless of the harvesting method.

On the harvesting systems there are two main areas where the majority of harvesting injuries are incurred, viz. at the mechanical bin filler of the harvesting system and during the picking action. Much optimization is needed in terms of machine design before injuries deriving from the transition from bin filler to bin will be eliminated. One of the major problems is the fact that a circular motion is used to fill a rectangular container. This leads to a pyramid forming in the center of the bin, which leads to fruit rolling down into the corners whilst colliding with each other and the sides of the bin at high velocity. There were also cases of fruit dropping through the rubber fingers of the bin filler onto fruit in the bin. As for damage that occurs during the picking action, the skill and technique of the picker as well as the environment in which the pickers are working seemed to play a major role. In this study it was observed that certain factors cause pickers to adopt picking techniques that result in unnecessary harvesting injuries. E.g., piece rate picking rewards pickers for increased productivity, but potentially to the detriment of quality of harvesting. Coupling piece rate bin prices to the quality of picking, i.e. rewarding a low incidence of harvesting injury, encourage both productivity and efficiency. However, this requires the rapid evaluation of harvesting injuries throughout the day in order to inform pickers of their performance. Another example is where producers want pickers to pick one fruit at a time because handling more than one fruit per hand may result in bruising (C. Groenewald, Personal communication). However, the fact that pickers are being paid piece rate actually incentivizes them to pick and hold on to more than one fruit at a time. Furthermore, it is difficult for pickers to remove one fruit from a cluster without the remaining detaching as well. It was observed that when fruit are evenly spaced and thinned to one fruit per cluster, pickers easily detached single fruit without dropping others. Thinning to single fruit may also increase fruit size. Larger fruit did not allow pickers to handle more than one fruit in each hand at a time, which eliminates the temptation/possibility of picking more than one fruit at a time. Producers should create an environment for laborers that incentivizes a working method that will deliver the desired results. Such an approach will decrease and simplify the extent and manner of monitoring needed.

Orchard actions other than harvesting

The economic analysis conducted as a part of this study showed that the cost effectiveness of a simple to operate, cheap laborer platform with a low running cost increased when used in combination with conventional practices for orchard actions other than harvesting. According to the analysis, the only scenario where it would have been economically feasible to substitute all ladders on the farm with laborer platforms is with a 100% gain in productivity for platform laborers over conventional laborers, which seems a highly unlikely outcome from the results of the productivity trials performed in this study.

In both Europe and the United States of America, laborer platforms are used for pruning, thinning, tree training and trellis construction. The platforms used range from simple self-built, tractor pulled platforms to advanced multilevel, self-propelled, over-the-row platforms (Herrick, 2014; Sazo et al., 2010). In this study we found that with the appropriate equipment, platforms can be used for such tasks in many South African deciduous fruit orchards, even older plantings with larger trees with bearing branches extending into the work row.

To maximize productivity gains with laborer platforms when performing these tasks, it is evident that producers should work toward simple tree management strategies with few instructions (Lehnert, 2013). E.g., the largest productivity gains in this study were seen in the summer pruning trials. Pruning instructions were simple, laborers had to remove strong upright shoots and in some cases remove one or two of the largest bearing branches on the tree. For conventional laborers such instructions result in the time spent working on the ladder decreasing relative to the time spent moving the ladder. Thus the laborer on the machine gains much more time for pruning when the ladder is replaced and because of this the interdependency of the laborers on the platform has less of an impact on productivity. If producers can find ways of making dormant pruning simpler, similar productivity gains can be expected. An example of such a simplified tree training system is the Tall Spindle training system developed in the USA for high density orchards. The training system decrease the complexity of trees and simplifies pruning. Mature tree pruning rules for this training system entail maintaining tree height at 80 to 90 % of row width, removing the two or three largest branches from the upper canopy with a beveled cut each year and columnarizing the remaining branches on the tree (Lehnert, 2013; Robinson et al., 2013). A shift towards more dwarfing rootstocks will also result in less growth that needs to be pruned away. A similar shift in strategy for fruit thinning will be more difficult. Whether such strategies will have the same effect under South African growing conditions needs to be tested. However, more laborer friendly trees with narrower canopies (Sazo and Robinson, 2012) will also increase the accessibility of fruit at thinning and harvest time. This will however pertain to laborers on platforms as well as ladders and in the end the difference between the two methods might still be insignificant and inconsistent.

Directly opposite to the mechanization trend, a certain Washington State producer have stopped using laborer platforms in order to do more detailed work more accurately (Warner, 2014a). This producer is of the opinion that by maximizing fruit yield and quality through precision farming practices, producers can earn more in returns than technology can save in cost. In concurrence with this an economic analysis conducted by (Robinson et al., 2007) showed that New York State producers can improve profitability more by planting high priced cultivars than by reducing production costs.

General remarks

Regardless of the practices and systems producers will employ, deciduous fruit farming and more specifically fruit harvesting will likely remain a labor intensive industry (Robinson and Sazo, 2013; Sarig, 2005). Thus producers need to focus on improving and investing in labor related factors such as training, management, motivation and satisfaction (Sazo and Robinson, 2012; Warner, 2014a). According to Warner (2014c), laborers are afraid to work to their full potential at piece rate because they think that producers will lower the price per unit when they start earning too far above minimum wage; this tendency was also observed by Cuskaden (1973) where an increase in bin price decreased productivity. The problem is that producers can perceive such a tendency as laborers being lazy and being satisfied with a daily flat rate. The aim of piece rate should be to encourage labor efficiency while rewarding excelling laborers rather than creating the impression that they are being taken advantage of. Californian producers are required to take it one step further by paying laborers for taking breaks when performing piece rate paid tasks (Warner, 2014c). If implemented correctly, paid breaks may benefit the farm by creating a positive laborer attitude as well as increase the productivity of laborers (Warner, 2014c). According to a labor specialist, breaks intended for resting (e.g. two ten minute breaks throughout the day) should be strictly monitored and implemented in order to reap the benefits thereof (Warner, 2014c). By paying each laborer a rate for rest time similar to the rate he/she would have earned while working may encourage laborer productivity whilst rewarding laborers on grounds of their performance. I.e. all laborers get the same amount of rest time, but more efficient workers are paid more for the break because they earn higher rates when working (Warner, 2014c).

Washington State producers found that when laborers are given a sense of job security, the labor supply becomes more stable (Warner, 2014a; Warner, 2014b). With a stable labor supply, producers may be willing to invest more in labor training, which in turn can result in long term benefits for the farm as laborers gain experience and become accustomed to the specific farm's operations (Warner, 2014a). Another labor related aspect that was prevalent in the study was the language barrier that exists between laborers and management staff on farms where no one sufficiently understand or speak the language of the other. (Sazo and Robinson, 2012) also points to the importance of good communication to allow for an exchange of ideas with laborers rather than a top down flow of instructions. The lack of communication can easily cause friction in the relationship between laborers and management, e.g. producers may be under the impression that laborers are cutting corners and are reluctant to follow instructions, whereas in some cases it might actually be that laborers do not understand the instructions and are afraid to ask. The language barrier was especially a challenge on the harvesting systems and platforms because of the new concepts and instructions that had to be explained and understood in order to make the team work together. With the teams where at least one of the laborers could interpret what was being said, information and advice could be given more directly and accurately. It also gave laborers the opportunity to give voice to their uncertainties.

Future orchards

From the work of Robinson et al. (2007; 2013) it is evident that new orchards should be established with mechanization in mind, but there should also be a focus on decreasing non-labor production costs, the improvement of fruit quality and the achievement of high early yields in order to make the orchard system competitive as a whole. Fortunately all of these factors point to similar characteristics for future orchards (Lehnert, 2013). According to (Robinson et al., 2013), there are five principles that guide the development of planting systems, viz.:

- High light interception (70 to 75% of available light) in order to obtain high yields, which necessitates trees to be tall.
- Good light distribution is facilitated by narrow tree canopies (1 m deep), which increases fruit quality.
- The need for high early yields have led to the use of feathered trees, higher planting densities, improved irrigation and fertilizing, minimal pruning at planting and branch bending.
- Simple and thin tree canopies are more suitable to partial mechanization of certain orchard tasks.
- The cost of the additional trees when planting density is increased will become larger than the gain in yield at some point.

It is on the grounds of these principles that the authors predicted that the orchards of the future will be tall (3 to 3.4 m), have an optimum planting density around 2500 trees ha^{-1} (2.7 to 3.5 m row spacing), will have narrow, simple but highly branched canopies which will give high early yields and allow for partial mechanization of certain orchard tasks (Robinson et al., 2013). One aspect producers should try and standardize on is row width. Uniform row width in all orchards will allow the same machinery to be used in all orchards and will lessen the need for machinery adaptability which may decrease initial investment costs (Herrick, 2014).

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Table 1: Effect of fruit size on harvesting productivity for apples in Washington State in the United States of America (USA), South Tyrol in Italy (ITA) and in the Western Cape in South Africa (SA).

Country	Fruit mass (g)	Actual harvesting rate (kg h^{-1})	Constant picking rate (fruit $min.^{-1}$)	No. of 360 kg bins filled per 9.5 h day
Fruit $min.^{-1}$ achieved with conventional harvesting ("Industry figures")				
USA	240	385	27	10.2
EU	190	140	12	3.7
SA	150	120	13	3.2
Fixed fruit $min.^{-1}$ rate for EU and SA set at USA rate (Showing the effect of fruit size).				
USA	240	385	27	10.2
EU	190	310	27	8.1
SA	150	245	27	6.4
Fruit $min.^{-1}$ required if SA and EU wants to achieve 385 kg h^{-1} with current fruit size.				
USA	240	385	27	10.2
EU	190	385	34	10.2
SA	150	385	43	10.2

ADDENDUM A. PHOTOS OF THE HARVESITNG SYSTEMS AND PLATFORMS EVALUATED IN THIS STUDY

Figure 1: Front view of the Hermes Tecno L during apple harvesting.

Figure 2: Side view of the Hermes Tecno L during apple harvesting.

Figure 3: Front view of the Hermes Tecno L used as a laborer platform for dormant pruning.

Figure 4: Front view of the Zucal Z11 during apple harvesting.

Figure 5: Rear view of the Zucal Z11 during apple harvesting.

Figure 6: Front view of the Zucal Z11 used as a laborer platform for dormant pruning.

Figure7: Front view of the N.Blosi platform during Nectarine harvesting.

Figure 8: Front view of the N.Blosi laborer platform used for fruit thinning.

ADDENDUM B. INSTRUCTION MANUAL FOR COST ANALYSIS MODEL OF PLATFORMS VERSUS CONVENTIONAL PRACTICE FOR DECIDUOUS FRUIT ORCHARDS

Background

This cost analysis model forms part of a research project initiated by HORTGRO Science to evaluate the use of harvesting systems and laborer platforms in deciduous fruit orchards under South African conditions. The effect of harvesting systems on harvesting-related fruit damage was investigated. It was found that these machines did not significantly decrease harvest-related fruit damage and therefore do not have a direct impact on the quality of the harvested fruit. Consequently it will not influence the prices received for fruit compared to conventional harvesting. It is for this reason that the economic analysis consists only of a cost analysis. The research showed that for certain orchard tasks in appropriate orchards, these machines do have the potential to increase laborer productivity. The model focusses on comparing the various costs involved when performing these orchard tasks either by conventional teams, laborers on platforms and a combination of conventional and platform teams. The model makes provision for the following orchard actions: trellis construction, tree training, summer pruning, dormant pruning, flower thinning, fruit thinning and harvesting.

For the scenarios where only conventional teams or platform teams are used, the number of teams, laborers and machines needed to complete an action in the specified amount of time is calculated. For the combination analysis, i.e., where both conventional teams and platforms teams are used, the number of platforms to be used in such a scenario is specified by the user and preference is then given to the platforms in the sense that work is always allocated to the platforms first. The work that exceeds the capacity of the platforms is then allocated to conventional teams. The number of conventional teams and laborers needed to complete the action in the required timeframe is then calculated.

Assumptions made in the modelling.

- All orchards are planted at the same tree density.

- Costs calculated pertain strictly to the activities performed in the orchard, i.e. the actual work done, and does not include e.g. the transport of full bins out of the orchard.
- The full purchase price of the platform is paid at the beginning of year one and the salvage value of the machine is received at the end of the last year of use of the machine.
- Two productivity levels can be specified for each action except for trellis construction where only one level of productivity can be specified.
- The platforms have a maximum lifespan of 40 years if annual use is low. The model automatically assumes that the platforms are sold at salvage price.
- The platforms are implemented into an already operational deciduous fruit farm where a fixed percentage of orchards are replaced each year.

How to use the model

Input sheet

This is the only sheet on which the user can enter and change parameters; all the calculations made on other sheets derive from this sheet. The blue cells have dropdown lists from which the desired option is to be selected and numeric values are to be entered in the green cells. To choose from a dropdown list, select the cell in which you want to specify a parameter, a downward facing arrow will appear to the right of the cell, clicking on this arrow will display the dropdown list, clicking on one of the options in the list will select that option. To enter a value into a green cell, select the cell in which the value is to be entered, type in the value and move on to the next cell via the arrow keys or by pressing enter.

Under the ‘Actions to include in analysis’ section, actions to include in the cost analysis are selected via the dropdown list method explained above. Selecting ‘Yes’ from the dropdown list will include that action in the analysis whereas selecting ‘No’ will exclude that action from the analysis.

Under the ‘General farm information’ section, information such as size of the farm, planting density, number of platforms, cost and lifetime of equipment and the cost and consumption of fuel is to be entered. The number of platforms specified here will be used in the combination analysis, i.e. the use of the specified number of platforms in combination with conventional practices will be compared to conventional teams and teams on platforms. The fuel consumption for platforms will be used in the calculation of platform costs and the ‘fuel consumption other’ is used for other equipment that may be used for conventional practice, e.g. petrol powered chainsaw.

Under the ‘General inventory information’ section, information for the calculation of the salvage value of the platforms, insurance costs, interest costs and the hourly maintenance costs of platforms and other equipment are specified. The maintenance costs of other equipment is used to calculate the maintenance of equipment used for conventional practice.

Under the ‘Labor structure and costs’ section, a subsection for all actions are provided but only the ones included in the analysis needs to be completed. For each action the various labor categories n that action together with the number of laborers in each position per team is specified. The monetary incentive refers to the method of payment, i.e. whether the laborers are paid piece rate, day rate or day rate with an additional piece rate on top (‘Day rate plus’). The appropriate option is to be chosen from the drop down list. Furthermore in this section, the daily wage of each position and the price per unit, when working piece rate or day rate plus, is specified.

Under the ‘Allocation of workdays’ section, the total number of allocable workdays are specified for conventional teams and for platform teams. The two need not be the same, e.g. when a platform is used on a farm in combination with conventional teams and the platform is not used for harvesting, there will be more workdays available for the platform than for conventional teams who are harvesting. I.e., the workdays needed for harvesting will in such a case not be available to for the conventional teams but will however be available to the platform. The ‘Total workdays allocated’ cells indicate the number of workdays that has been used for specific actions in the ‘Workdays allocated per action and productivity outputs’ section. The ‘Allocable workdays remaining’ cells indicate the number of workdays that can still be allocated, if these cells are red and contain a negative value, it means the used workdays exceed the total number of allocable workdays available and that less workdays should be allocated to some of the actions. If these cells are yellow, it means that the used workdays does not exceed the total number of allocable workdays available.

Under the ‘Workdays allocated per action and productivity outputs’ section a subsection for each action is provided but only the ones included in the analysis needs to be completed. For each activity the number of shifts per day and the number of hours per shift needs to be specified. In a case of more than one shift per day, the same platforms are used in all shifts but a different team of laborers are needed for each shift. A maximum of two levels of productivity can be specified for each action, except for 'Trellis construction'. For each level of productivity the number of hectares of orchard that can be completed at that level of productivity needs to be specified as well as the actual level of productivity and allocated workdays for that action at the level of productivity. In the case of a certain action being repeated in an orchard, e.g. tree manipulation, the hectares and allocated workdays for that action at the specific productivity level should be multiplied by the number of times the action is repeated. The values in the 'Workdays needed for one team' rows indicate the number of workdays needed for one team to complete the action as specified. This serves as an aid when deciding how much workdays should be allocated to each action at each specified productivity level. If the cells are red, it means allocated workdays are less than needed and that additional teams will be required to complete that action in the specified number of workdays. If the cells are yellow, it means that the number of workdays specified are more than needed for one team to complete the action and the excess workdays can be allocated elsewhere. Furthermore the number of workdays available for each action is dependent on the cultivars planted on the farm and the production schedule of that farm.

If an action is not included in the analysis and workdays are allocated to that action, an error message will appear instructing the user to either leave the cell blank or to include the action in the analysis.

Summarized output sheet

The 'Platform capacity' section shows the number of hectares a platform can complete for each action at the specified productivity levels. The 'Man hours needed per ha' section compares the man hours needed to complete each action for a hectare of orchard at the specified levels of output for platform teams and conventional teams. The 'Summary' section displays the cost savings that can be achieved per year with the number of platforms as specified on the input sheet. It also shows the Net Present Value and the Annualized Net Present Value of the cost savings incurred during the lifetime of the platform.

Inventory partial budget sheet

This sheet indicates the lifetime of equipment, annual hourly use of equipment and the calculation of various costs for equipment used in the analysis. All of these costs are shown for a single platform and a single ladder.

Partial budget sheet

This sheet summarizes the labor, diesel, maintenance, depreciation, interest, insurance and total costs for all the actions included in the analysis. The costs are shown for farming scenarios that employ only conventional teams, only platforms or a combination of conventional teams together with a specified number of platforms. Furthermore the number of teams needed (Columns C, F, J and L) as well as the number of laborers needed (Columns D, G, K and M) for each action is shown. The cell in the team columns that is red indicates the maximum number of teams needed on the farm and this number is used to determine some of the fixed costs. This information is summarized into total costs for each farming scenario from which the differences between the various scenarios are calculated.

Capital equipment planning sheet

This sheet shows the purchase price, annual costs savings and lifespan of the platforms. This information is used in the calculation of the payback period in years, Net Present Value of the total cost savings over the lifetime of the platform(s) and the Annualized Net Present Value of the total costs savings.

Calculation of costs for the specific actions

For further detail, separate sheets showing the calculation of labor, diesel, maintenance and depreciation costs are provided for each action at each specified level of productivity. These sheets use the parameters specified on the 'Input sheet' to calculate the various costs associated with each action. The man hours and laborers needed for each team and machine as well as in total are shown in columns G and H. Hours needed and the various costs are first calculated on a per hectare basis and are displayed under the 'Per ha' section. This information is used to calculate the total cost of the action for conventional teams, platforms and a combination of conventional teams and platforms for the number of hectares and at the productivity levels as specified for each action. Furthermore, these sheets provide the daily wage received by each labor level for that action and can aid decision making with regard to piece rate pricing.

ADDENDUM C. PERSONAL COMMUNICATIONS REFERENCE LIST

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