EXACTLY HOW MUCH WATER DO APPLE TREES REALLY NEED?

+ COMBATTING INTERNAL BROWNING
ISSUE THEMES

In each issue the Fresh Quarterly will address certain themes pertaining to crop production, crop protection and postharvest.

This issue’s themes are:

- **Plant water use** for crop production
- **Internal browning in apples** for postharvest

Happy reading.
“An investment in knowledge pays the best interest.”

So says one of America’s founding fathers, Benjamin Franklin. Ol’ Ben was big on self-education and believed if you want to get a good return on yourself, your time, your effort and your money, you have to invest in knowledge.

Franklin shared that advice in the 1700s. Fast-forward to the 21st century and humanity has become intellectually despondent. Our minds are over-saturated with fast information, but is that what we need?

When we set out to create the Fresh Quarterly, we aimed to create a magazine that busy growers wouldn’t mind taking the time to read. We believe learning must be interesting, absorbing, and relevant. We want to keep you informed and ensure those dividends keep rolling in.

But for this to happen we need you, our growers, to read and engage with the copy, and with us. Let us know what you want to read, and what you think of the articles.

As the world keeps revolving, we forget that it’s also changing. Somewhere along the line we must learn and adapt to survive and excel. Clinging to the past or our comfort-zones, and ignoring the present and future, will mean succumbing to eventual entropy. We need to educate and apply ourselves to face the challenges the industry will continue to experience. Agriculture is dynamic; maybe we should be too.

In this issue we delve into plant water use and internal browning in apples. We hope to provide insight and solutions to these contentious topics.

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Every fruit farmer knows irrigation is an essential part in growing the perfect crop. Horticulture experts Stephanie Midgley, Wiehann Steyn and Michael Schmeisser explain why this is, and how trees actually use water.
Plants need to take up carbon dioxide for photosynthesis to take place.

Carbon dioxide enters the leaf through very small openings on the leaf surface, called stomata (*Huidmondjies* in Afrikaans).

The space within the stomata is saturated with water vapour while the air outside of the leaf is generally not saturated during the day.

Due to the difference in vapour pressure in the air outside the leaf and the vapour pressure inside the leaf, water moves out of the leaf while the stomata are open. This process is called transpiration.

There is a trade-off between plant productivity and water lost through transpiration. Stomata can close partially or fully to manage water loss through transpiration, but this impacts on the uptake of carbon dioxide, which may again impact on dry matter production, i.e. fruit growth, sugar levels, vegetative growth, sugar and metabolite production, energy for various processes, etc.

Factors that affect the water vapour pressure in the air can affect the rate of transpiration.

- Low relative humidity at high temperature equates to a low air water vapour pressure and therefore a strong driving force for transpiration.
- Wind removes the more saturated layer of air in immediate contact with the leaf and therefore also increases transpiration.
- Nets can increase the water vapour pressure of the orchard air and decreases wind, thereby decreasing the driving force for transpiration.

Deciduous fruit trees will allow high levels of transpiration and therefore also high rates of photosynthesis until the water pressure in the plant becomes quite low (or the water tension within the plant becomes quite high).

The water in the plant can become under considerable tension on days of high transpiration when supply to leaves through the roots and stem cannot keep up with the demand. The plant finds it more difficult to access soil water as the soil dries out. At a certain soil water moisture level, the plant cannot take up any water. Due to limitations to the rate at which water can flow through the plant, water demand can outstrip supply even when the soil contains enough water. Partial to full closure of stomata at this point can restrict transpiration, but will limit photosynthesis due to lower uptake of carbon dioxide.

The following factors affect water use at an orchard level:

- The water use of deciduous fruit trees is linked to number of stomata, which relates to the leaf area per ground area. More stomata (i.e. leaves) per square meter of orchard floor equals higher transpiration rates. Yield can also relate to the effective leaf area since the level of light interception affects the potential photosynthesis that can take place. We speak about effective leaf area, because leaves on vigorous shoots may use a lot of water, yet contribute little to tree productivity.
Cover crops also use water but provide biological functions to the orchard, such as serving as reservoirs for mite predators.

Evaporation from the bare orchard floor contributes to total orchard water use. The greater the area of orchard floor wetted during irrigation, the greater the potential evaporation water loss—this is why drip irrigation is more effective than micro irrigation.

Drainage or run-off of excess irrigation water contributes to orchard water use but contributes nothing to productivity—it’s a dead loss.

Use of water for other purposes than to supply the transpirational needs of the plant, e.g. overhead or floor level evaporation cooling, should be considered very carefully since it does not directly contribute to productivity—although it may affect fruit quality.

Given the trade-off between transpiration and photosynthesis, fruit growers should aim to maintain soil water levels so to not have photosynthesis limited by water restriction, while working hard to prevent or restrict any non-beneficial water use by the orchard. ❍
thirst trap

How much water do high performing apple orchards need?

Words by Esté Beerwinkel
A lingering drought and remarkably high yielding orchards compel farmers to give their irrigation practices a second thought. A four-year project set on establishing how much water apple orchards need concludes that it all boils down to orchard management.

Water is a critical, but finite resource. The world revolves around it, and farmers know this acutely.

At the beginning of this decade, the United Nations’ Food and Agriculture Organisation reported South Africa’s total water withdrawal at 12 496 million m³, with irrigation accounting for 62% of it.

Since then, farmers had to reconsider their water-use practices. In 2015 a drought tightened its grip on the Western Cape. Also, the water requirement for apple orchards of 6 000 m³ per hectare, based on past research, may no longer be accurate due to changes in planting systems and a general, steady increase in yields. Exceptionally high yielding apple orchards, producing more than 100 tonnes per hectare, have become commonplace locally and elsewhere in the world.

This is why, four years ago a team of researchers in the deciduous fruit industry embarked on a mission to figure out “how much water apple trees need”.
Research team leader, Dr Sebinasi Dzikiti of the Council for Scientific and Industrial Research, determined that apple trees in a high production orchard ‘drink between 80 and 136 glasses’ of water a day—or 30 000 to 45 000 litres per hectare per day depending on leaf area. “But it’s more complex than that as other factors such as the local microclimate, rootstock, crop load etc. also influence orchard water use”, according to Dzikiti.

When they set out to establish the water requirements of apple orchards, the researchers had the following focus areas; 1) to determine the maximum unstressed water requirements for high yielding orchards, 2) to quantify how orchard water use changes from planting until full-bearing age, and; 3) to establish whether fruit quality is affected by how much water a tree receives. A checklist was designed to select qualifying orchards for this study:

a) Orchards needed to be well-managed.
b) Orchards needed to be located in the Elgin, Grabouw, Vyeboom and Villiersdorp (EGVV) or Koue Bokkeveld regions
c) Orchards needed to be either ‘Golden Delicious’ or ‘Cripps’ Pink’. ‘Golden Delicious’ was chosen because it’s the major cultivar in South Africa, and bears high yields. ‘Cripps’ Pink’ was chosen due to its high yields, high value, and long growing season, which may increase seasonal water requirements.
d) Irrigation system needed to be micro sprinklers as it is the industry norm.
e) Orchards needed to have a deep soil profile for installation of soil moisture probes, and cover a large area for accurate measurement of evapotranspiration.
f) Trees needed to be on the industry standard M793 rootstock.
g) Mature orchards needed to yield an average of 100 tonnes/ha or more.

Dzikiti says finding suitable orchards was the most challenging aspect of this study. “It proved harder than we initially thought to source suitable orchards. Sometimes we also dealt with unsuitable rootstocks, small orchard sizes, and stony soils in the EGVV. However, the cooperation from the farmers was a lekker highlight.”

After finding suitable orchards the research team set out to quantify the actual tree water use every hour throughout the growing season using sap flow sensors installed on three to six trees per orchard. Since tree sizes differ between orchards, the tree-specific data was then extrapolated to a per hectare basis.

“We also measured the soil water content in the root zone, orchard microclimate, tree and fruit growth, yield quality and quantity, irrigation volumes, and orchard evapotranspiration,” Dzikiti says. “In addition to tree transpiration we also directly measured orchard floor evaporation in some instances to get an overarching picture of orchard water use”.

Dzikiti and company also monitored newly planted orchards in addition to the full-bearing orchards. This was all done using the following techniques and technologies that collected the data hourly throughout the growing season for some variables:

a) sap flow sensors measured tree transpiration,
b) eddy-covariance and Fruitlook for orchard scale evapotranspiration,
c) weather stations monitored orchard microclimate,
d) dendrometers measured stem and fruit growth,
e) pressure chambers measured plant water stress levels,
f) infrared gas analysers measured gas exchange (leaf transpiration and photosynthesis),
g) time domain reflectometers measured soil water content, and;
h) leaf area index meters measured canopy development and seasonal changes.

The research team concluded that orchard leaf area is the main factor that determines how much water an apple orchard needs. While other key determinants of how much water apple trees need are climate, and crop load, leaf area plays the bigger role. This fact, Dzikiti says, is met with some contention. “Some in the industry have argued
against our results which show leaf area rather than crop load as the main determinant in orchard water usage. They argue that the bigger the crop, the more food the tree will have to generate for the fruit. While this is true, you can also have an orchard with a larger leaf area and less fruit that uses the same amount of water as the orchard with the larger crop load but smaller leaf area.”

Dzikiti continues to explain this, using findings from their study to illustrate. “For example, mature ‘Cripps’ Pink’ orchards, which had more open canopies and lower leaf areas for reasons such as red colour development, transpired 5 900 to 6 300 m³/ha/season. On the other hand, mature ‘Golden Delicious’ orchards, which had more closed canopies and a higher leaf area to protect the fruit against sunburn used 7 600 to 7 900 m³/ha/season. However, the ‘Cripps’ Pink’ orchards which had a relatively low water use had higher yields averaging 110 tonnes per hectare compared to around 98 tonnes per hectare for the ‘Golden Delicious’ which had higher water use rates”.

The seasonal total evapotranspiration, which equals the orchard water requirements, ranged from 9 500 m³/ha/season in the full-bearing ‘Cripps’ Pink’ to around 10 500 m³/ha/season in the ‘Golden Delicious’.

Dzikiti furthers that in young orchards, more than 60% of the evapo-
transpiration in summer came from the orchard floor compared to around 18% in full-bearing ‘Golden Delicious’ and 32% for ‘Cripps’ Pink’ at maximum leaf area. “This is because younger orchards have fewer leaves, thus more water goes to the cover crop or evaporates from the orchard floor; mature orchards have more leaves so the trees, not the orchard floor, use the water.”

On whether the study’s results also apply to other cultivars such as ‘Royal Gala’, or other pome fruit such as pears, Dzikiti says maybe, but further research is needed to confirm this.

Whether fruit quality is affected by trees receiving less water, Dzikiti says the jury is still out.

Our study did not address this. The literature shows that there are potential negative effects, depending on the level and timing of stress—see QR codes for an article on this on next the page.

“Farmers should be wary of “overloading” ‘Golden Delicious’ trees; these trees indicate a limit to economic water productivity (R/m³) resulting from small fruit size at very high yield numbers.” Physical water productivity (kg of fruit per m³ of water used) increased with increasing yield. However, economic water productivity levels off.

According to Dzikiti producers can use the results from this study as a guide for improving irrigation practices (for example irrigation scheduling, water allocation and so on), and how to do more with less.

“By using water saving techniques such as drip irrigation to reduce evaporation from the orchard floor, shade nets to reduce evaporation and tree transpiration, and by choosing dwarfing rootstocks to reduce unnecessary shoot growth, producers can get more fruit with less water—the key is effective orchard management.”

KNOCK-OUT ROUND

WHICH USES MORE WATER: LEAF AREA VERSUS CROP LOAD

Scenario one: You have two ‘Golden Delicious’ orchards with the same crop load, but one has more leaves than the other—the orchard with more leaves will use more water.

Scenario two: You have two orchards with the same leaf area, but the crop load differs—the orchard with the larger crop load will use more water.

Probability one: Leaf area effect in terms of water use is larger than that of the crop load.

Probability two: If I lessen my crop load during drought conditions, I’ll use less water; provided I don’t stimulate any further growth.

Probability three: If I reduce both the crop load and leaf area, the water conservation effect will be greater.
WATER USE RECOMMENDATIONS

Exceptionally high yielding apple orchards can be sustainably farmed in the Western Cape, but effective canopy management is essential to avoid excessive water use. Consider the following recommendations:

1. Golden Delicious crop load should be managed carefully, high fruit numbers reduce fruit size and the pack out of export quality fruit.

2. As orchards mature and achieve higher yields, physical and economic water productivity increase. However, in Golden Delicious there appears to be a ceiling to economic water productivity which is attributable to small fruit size at a very high yield. Don’t overload the trees.

3. Currently, orchard floor evaporative losses in young micro-sprinkler irrigated orchards are very high. It is crucial to implement water saving techniques such as accurate irrigation scheduling, mulching, drip irrigation, and shade nets to reduce water wastage.

4. Apple growers with limited or unreliable access to water resources should consider focusing on high value cultivars such as Cripps’ Pink, Rosy Glow etc. for new plantings, and gradually remove lower value cultivars. This would gradually increase the farm level water productivity and maximise profitability for every unit of irrigation water.

5. Trees on more dwarfing rootstocks with less vigorous growth, as well as trees under shade netting that reduces evapotranspiration could help with water saving.

PROJECT DETAILS

**Aim:** To determine the water use, yield and quality of selected high performing apple cultivars from planting to full-bearing in selected climatic zones and specific soils.

**Duration:** April 1, 2014 to March 2018

**Funded by:** Hortgro, Water Research Commission, Parliamentary grants to Council for Scientific and Industrial Research (CSIR) and the Agricultural Research Council (ARC), National Research Fund (Thuthuka Grant), NRF-DST Professional Development Program, CSIR Young Researcher Establishment Fund

**Team:** Dr Sebinasi Dzikiti (CSIR), Dr Mark Gush (CSIR), Dr Theresa Volschenk (ARC), Prof Stephanie Midgley (Stellenbosch University), Dr Elmi Lötze (Stellenbosch University), Dr Michael Schmeisser (Stellenbosch University), Dr Nicky Taylor (University of Pretoria)

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Every year the Western Cape loses ±38 million m³ of water from its major water supply system—the equivalent to the whole Upper Steenbras Dam—due to invasive alien plants. Dense stands of exotic tree species such as pines, wattles, eucalyptus, poplars, Australian acacias, Hakea and the like are responsible for a broadly estimated 1 000 m³/ha/year of water loss in the Western Cape. This is because invasive alien plants (IAPs) have increased evapotranspiration rates relative to the indigenous vegetation such as fynbos.

Drs Mark Gush and David le Maitre of the Council for Scientific and Industrial Research (CSIR), say that based on dedicated studies water loss caused by following species are:

- Pines (*Pinus pinaster /radiata*) = 430–2 000 m³/ha/year;
- Riparian eucalypts (*E. camaldulensis*) = 2 000 m³/ha/year;
- Riparian wattles (*Acacia mearnsii*) = 450–1 350 m³/ha/year;
- Riparian poplars (*Populus canescens*) = relatively low in comparison, 200 m³/ha/year.

Gush says riparian areas, areas next to rivers and streams, have greater water loss estimates compared to upland areas. Tree size and density also has an influence.

“The water extracted from the soil by IAPs is generally lost to the catchment—trans-ported by wind to distant areas or the ocean—and is consequently expressed in the form of stream-flow reductions. The aftermath of these reductions to ‘catchment yield’ or useable water in Western Cape Water Supply System (WCWSS) is substantial—approximately 38 million m³ of water per year.”

But how can the agricultural community help relieve this issue? Gush suggests “never wasting a good crisis”.

“Agriculture uses both surface water (rivers and dam) and groundwater. The current drought created direct competition for the remaining water between domestic and industrial use on the one hand and irrigated agriculture on the other. Therefore, to secure more water sources organised agriculture needs to lobby for increased investment in effective clearing of invasive species—prioritising mountain catchments, riparian zones and aquifers.”

So, what is the impact of this on fruit production—if one considers that 22 000 ha of apples will have an approximate water requirement of 132 million m³ (working with an average of 6,000 m³ ha including young orchards)?

“Stream-flow reductions and lower dam levels have led to water restrictions, and difficult decisions for fruit producers. Less orchard irrigation is one such consequence. Clearing IAPs from water catchment areas that supply dams can help top up water supplies.
Using the average estimates stated above, every six hectares of IAPs cleared could yield enough water for one hectare of apples—6 X 1 000 m³/ha/year. In all cases, clearing riparian areas would yield a greater response (>3 times more water per unit area cleared). Clearing densely invaded areas would also be of proportionally greater benefit.

Dr Le Maitre notes that the current levels of IAPs clearing aren’t keeping pace with the rates of its spread.

“IAPs are estimated to be increasing by at least 5% annually. Even more concerning is that if clearing of IAPs were stopped, we could expect a reduction in stream-flow of 130 million m³ per year by 2045—the equivalent of the Berg River Dam will be lost annually.”

According to research by Gush, Le Maitre and the CSIR team, the solution lies in replacing IAPs with lower water using indigenous species—and curbing takeover of water source areas by IAPs.

“Indigenous species such as fynbos allow most of the rainwater to run off into our rivers and reservoirs, and also help to keep water in high-lying wetlands, slowly releasing it throughout the year. Fynbos catchments cover 8,47 million hectares or 6,7% of the entire country, and contribute 13% of the country’s surface water. The stats are:

- Fynbos catchments yield a mean annual runoff of 6 628 million m³ per year.
- Water source areas cover 2,16 million hectares or 26% of the total fynbos catchment area.
- These areas produce a mean annual runoff of 5 032 million m³ per year or 76% of the total fynbos catchment runoff.
- This is the equivalent of 2 323 m³/ha/year—an unmatched six times the national average runoff per unit area.

“Relatively small water source areas therefore produce disproportionally greater volumes of water and are critical for water supply.”

Gush and Le Maitre reiterate that although effective IAP clearing programmes are expensive, the benefits far outweigh the cost.

“IAP clearing programmes require properly staffed, managed and resourced, with skilled staff in oversight roles. The removal of IAPs has the potential to release an additional 1 000 m³ per year for every hectare cleared and rehabilitated to fynbos. This process will cost an estimated R80 million/year to maintain clearing within the WCWSS and R200 million/year across the whole province, but every cubic metre released improves water security and sustainability.”

WHAT CAN GROWERS DO TO HELP?

- Landowners can assist by clearing their farm-land of invasive alien plants. Start high-up and work your way down—target dense infestations, particularly in streamside areas.

CLEARING OPERATIONS AND SUGGESTIONS

- Further research and identification of increasingly effective control measures and technological advances, such as using drones to identify IAPs, can help with more cost-effective clearing.
- Clearing operations in place include: Working for Water, Cape Nature, Land-user Incentives, and LandCare. Scan the QR Codes below to learn more.
RESEARCH INVENTORY:
A list of plant water use research projects and publications

This series of plant water articles was compiled using information from industry funded research spanning 16 years.

COMPLETED PROJECTS

2002  Development and evaluation of a model for water use in deciduous fruit orchards and scheduling of irrigation with the aid of meteorological data (Theresa Volschenk)

2006  The influence of climate stress and source/sink manipulations on gas exchange, size and colour development of bi-colour apples (Stephanie Midgley)

2007  Effect of intensive water and nutrient management on physiological and horticultural aspects of apples and nectarines (Piet Stassen)

2008  The effect of varying drip irrigation frequencies on apple tree production and water use (Theresa Volschenk)

2011  The effect of water deficit on apple tree performance (Theresa Volschenk)

2012  The effect of water deficit on pear tree performance (Theresa Volschenk)

2013  Quantifying the effect of inorganic and organic mulches of two soil types on nutrient uptake and fruit quality of ‘Cripps’ Pink’ apples (Elmi Lötze)

2015  Inherent and acquired resistance to fruit sunburn and poor colour in various apple/pear cultivars (Wiehann Steyn)

2017  Water relations and sunburn in pome fruit (Wiehann Steyn)

2018  Quantifying water use of high performing commercial apple orchards in the winter rainfall area of South Africa (Sebinasi Dzikiti)

2018  Evapotranspiration of high performance apple tree orchards (Theresa Volschenk)
CURRENT PROJECTS

• Establishing quantitative relationships between water relations, growth, yield and quality of high performing commercial apple orchards (Stephanie Midgley)

• Effect of irrigation on the performance of young apple trees in newly established orchards (Eduard Hoffman)

• Sensitivity of various apple rootstocks to water stress (Stephanie Midgley)

NEW PROJECTS

• Investigating the potential of fixed and draped netting technology for increasing water productivity and water savings in full bearing apple orchards under micro-irrigation (Stephanie Midgley)

• Water use of pome and stone fruit: knowledge status, relevance and gap analysis (Caren Jarmain)

PUBLICATIONS

Book chapters


Scientific journal papers


Scientific conference proceedings


INTERNAL BROWNING IN ‘FUJI’

What have we learnt since 2015?

“In physiological disorders you get an alignment of stresses,” says Dr Ian Crouch, director of research at ExperiCo. “All the factors just line up—like dominoes.” When certain growing conditions and postharvest practices combine, one falling domino can trigger a disaster. Words by Anna Mouton

In 2015, ‘Fuji’ apples shipped to Asia developed severe internal browning—up to 80% in some batches. Ever since, researchers in the fruit industry set out to find why this happened, and how to prevent future occurrences.

GETTING TO KNOW INTERNAL BROWNING

The clue is in the name: internal browning refers to brown discoulouration of fruit flesh. The peel is undamaged. Internal browning is not the only disorder to cause browning, but the brown areas remain firm. In other physiological disorders, the flesh becomes soft. ‘Cripps Pink’ clones and ‘Fuji’ apples have been most affected by internal browning in South Africa.

‘Fuji’ has been grown locally since the mid-1990s. “And right back then, when Unifruco Product Development was looking at the cultivar, they found that, even though it tasted wonderful, it had browning issues,” recalls Crouch. Even so, ‘Fuji’ was a success and orchards have increased fifteenfold between 1995 and 2017. No surprise then that the losses of 2015 prompted a concerted research effort.

Crouch describes a multipronged attack. The first step was to share pictures and a description of the disorder to an international network of postharvest scientists. Feedback soon pointed to carbon dioxide as a potential cause of internal browning. “One of the people who really made an impact on us was Professor Emeritus Michael Reid, from the University of California, Davis,” says
Crouch. The industry subsequently brought Reid to South Africa as a technical expert.

Crouch also conducted a literature review. “We firmly believe that the cheapest research is somebody else’s,” states Crouch. “I read all the articles I could find on internal browning.” Available research confirmed the role of carbon dioxide (CO₂) injury. Hortgro published a summary of the literature review, including guidelines for control, in a Fresh Notes (see QR code on next page).

CO₂: NOT JUST A GREENHOUSE GAS

So how does carbon dioxide cause browning? “Any ripening fruit produces CO₂,” explains Crouch, “and if that CO₂ can’t leave the fruit, it leads to leaking of phenolics in the cells and that gives browning. Factors that prevent normal diffusion of CO₂ out of the fruit promote browning.” Ethylene contributes to browning by increasing respiration and therefore CO₂ production. Ethylene may also indirectly affect the leakiness of cell membranes to phenolics.

“Normally when we talk carbon dioxide damage, we’re thinking of buildup in controlled atmosphere storage or in bags,” says Crouch. “What we didn’t realise is that, even in the orchard, there are all kinds of factors that also prevent diffusion of CO₂—like the density, peel and size-volume ratio of the fruit.

“We put together projects linked to some of the hypotheses around CO₂. But we can’t reproduce all of the dominoes,” adds Crouch. “You can’t make a fruit do something that it’s not programmed to do. That’s always a problem in research.”

Experiments showed that exposure to extreme CO₂ levels immediately after harvest can produce internal browning. Apples from different orchards vary in their re-
“When certain growing conditions and postharvest practices combine, one falling domino can trigger a disaster.”

sponse with some more susceptible than others. “The idea was to rank orchards according to this simple test,” clarifies Crouch, “to see if we could link the predicted risk to actual development of internal browning in storage.

“But we only got low levels of browning during storage, so it was difficult to show a correlation.” Preharvest risk factors identified so far include suboptimal harvest maturity, harvest after 180 days post bloom and previous occurrence of internal browning in an orchard.

KEEPING THOSE BROWNING BLUES AWAY

At harvest, fruit should be moved to the cold store as soon as possible—but not cooled too quickly! Fruit harvested on a warm day can undergo severe stress during rapid cooling. “A darker fruit like a ‘Pink Lady’ will be hotter than ambient,” Crouch points out. Reduce stress by using step-down cooling. Start storage at 2.5˚C and low humidity, followed by gradual cooling over seven days.

“Even if you’re going to put fruit in controlled atmosphere, don’t do it immediately,” advises Crouch. “Give it a couple of weeks to acclimatise. Cooling is one stress and controlled atmosphere is another. So it’s like a domino effect with all these stresses on top of preharvest stresses—we don’t even know what all of those are.”

Long-term storage under regular atmosphere increases the prevalence of internal browning. Browning may occur as early as three weeks into storage, so fruit stored under regular atmosphere should be packed no later than three weeks post harvest.

Keeping CO₂ levels to a minimum—ideally less than 0.5%—is essential for controlled atmosphere storage. This is most critical during the first four to eight weeks. Note that late-harvested fruit is not suitable for controlled atmosphere storage.

CO₂ buildup in packaging and during transport must be avoided. Increase the re-cooling period from two to five days and use delivery air not colder than –1˚C.

The guidelines for control have recently been updated and include best practices for both internal browning and lenticel breakdown in ‘Fuji’ apples.

CRACKING UNDER PRESSURE

“The problem with research is that it’s very difficult to predict when you’re going to have the same problem,” observes Crouch. Internal browning has receded since 2015, hampering efforts to understand the disorder.

New research suggests that markets affect internal browning. Crouch wonders whether better cold-chain management on the receiving end is one reason why browning has decreased. “Maybe they’re now trying to look after the fruit better when it arrives.”

But producers have no reason to relax. Crouch says that cracking is the new problem with ‘Fuji’ apples—to the extent that some producers are removing trees. “We may be able to solve the browning. The cracking may be something that we can’t prevent.” FQ
“What’s amazing about browning in the ‘Cripps’ Pink’ clones is that there are so many kinds,” says Dr Elke Crouch, postharvest physiology and technology researcher at Stellenbosch University. “And every single type of browning is different: both in the factors that cause them and how we rectify them.”

Browning of the flesh in ‘Cripps’ Pink’ clones fall into five categories: diffuse, radial, combination and bulge browning, and carbon dioxide (CO₂) damage. Diffuse browning is the most common kind in South Africa. “The rest of the world has a problem with radial browning,” states Crouch, “and that’s difficult to rectify because we don’t really know why it occurs.”

In diffuse browning the cortex is affected whereas in radial browning it’s the vascular tissue. Combination browning shows discolouration of both areas. Browning is not present at harvest—it develops after several months of storage.

GETTING RID OF DIFFUSE BROWNING

Crouch and her colleagues have been researching browning for several years. “We started with postharvest—I think the postharvest work is really important because that’s where you can make a big difference.

“You have to harvest at less than 40% starch breakdown. You cannot store long-term if you don’t have that. If you harvest over 40% starch breakdown, your chances of getting diffuse browning are really good.”

The second critical factor is storage temperature. “It seems like slightly higher storage temperatures actually prevent diffuse browning,” explains Crouch. She recommends storage at 2°C. Application of 1-MCP (1-methylcyclo-
DIFFERENT TYPES OF INTERNAL BROWNING

1. DIFFUSE BROWNING
2. RADIAL BROWNING
3. COMBINATION BROWNING

PHOTOS PROVIDED BY DR ELKE CROUCH
propene or SmartFresh™ will reduce the risk of greasy fruit.

Studies of pre-harvest variables indicate that factors which speed up ripening—such as sandy soils and younger trees—also increase the risk of diffuse browning. “We found that anything that enhances maturity led to more diffuse browning. Or combination browning, because you need diffuse browning to get combination browning,” says Crouch. “Radial browning wasn’t related to any of those factors.”

According to Crouch, the danger of diffuse browning is greater when the season has favoured early ripening. Producers need to be aware of this risk and adjust harvest schedules and storage decisions accordingly.

**OTHER SHADES OF BROWNING**

Although researchers overseas found harvest maturity to affect radial browning, this was not seen in South African studies. Instead, radial browning seems to be associated with seasonal factors, especially cooler seasons. “I think a lot of people are going to get radial browning this season,” warns Crouch. “I already see the claims coming through.

“Radial browning, like diffuse browning, only manifests with longer-term storage—three to four months under controlled atmosphere. And you definitely want to take fruit out after five months if there is a risk of either of these.”

Crouch advises non-destructive sorting when radial browning is found on opening a room. In their study, radial browning didn’t increase much during shelf-life, so removal of affected fruit prior to export should go a long way toward avoiding claims.

In other countries, radial browning occurs in areas that accumulate more than 1 100 GDD (growing degree days) between full bloom and harvest. In these regions, it manifests during seasons with GDD in the range 1 100 to 1 700. Lower spring temperatures seem to increase later risk of radial browning, perhaps by affecting early cell division and expansion processes.

In contrast, bulge browning occurs when fruit is misshapen and browns on the deformed side. “The theory is that pollination was faulty,” says Crouch, “that something went wrong at fruit development.” The bulging side of the fruit is weaker and more susceptible to browning. This problem has not attracted much research interest—the prevalence seems low and badly shaped fruit are easily identified and removed during sorting.

CO₂ injury is characterised by small cavities in the cortex. It develops due to incorrect storage practices. “If you don’t cool the fruit down properly before you put it under controlled atmosphere,” explains Crouch, “then the fruit respires causing carbon dioxide buildup and low oxygen levels. ‘Pink Lady’ especially doesn’t like that and develops carbon dioxide injury.” High respiration rates and rising carbon dioxide levels in a cold store indicate a problem and need investigation.

**DIGGING DEEPER INTO BROWNING**

“There’s still a lot of research to be done,” stresses Crouch. An ongoing project is looking at long-term—up to nine months—storage. “Nine months and a six-week shipping period and then seven days shelf-life: it’s risky and this season was very successful.

“Our last evaluation was toward the end of February this year, of fruit harvested last year in April—almost a year. We had very good results. But we need to repeat it,” cautions Crouch. “We need to confirm that it wasn’t just a good season.”

Orchard effects on browning also require further study. “The orchard differences are huge so there are definitely orchard factors involved in all of these types of browning,” says Crouch. “So it’s easy to say: ‘Harvest at the right time, store correctly’ but then one goes back to the orchard factors and you can’t really put your finger on the cause.”

Crouch is optimistic that diffuse browning in ‘Cripps’ Pink’ clones is controllable. “I think the problem is not as bad as it was because more people are doing what they’re supposed to be doing. But I think we also had a tough season—fruit are generally riper, so maybe things might be popping out. And we had a cool spring, so we are likely to see more radial.”

FQ
RESEARCH INVENTORY:
A list of internal browning in apples research projects and publications

Below you can find a list of completed industry funded research projects and literature surrounding internal browning in apples.

COMPLETED PROJECTS

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<tr>
<th>Year</th>
<th>Title</th>
<th>Authors</th>
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<tbody>
<tr>
<td>2010</td>
<td>Modelling internal browning of ‘Pink Lady’/’Cripps’ Pink’ apples</td>
<td>E Lötze</td>
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<td>2015</td>
<td>The relation between Cripps’ Pink internal browning and pre-harvest</td>
<td>E Crouch, H Bergman</td>
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<td>temperatures, mineral nutrition, tree age, soil type etc. in two</td>
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<td>production areas after long term CA storage and the evaluation of</td>
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<td>the non-destructive NIR techniques for sorting internal, brown fruit.</td>
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<td>2016</td>
<td>Physiological profiling on ‘Rosy Glow’ apples harvested at different</td>
<td>H Tayler</td>
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<td></td>
<td>maturities, with special reference to internal browning development</td>
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<td>potential (H, Taylor)</td>
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<td>2018</td>
<td>Harvest and storage condition plus duration influencing internal</td>
<td>E Crouch</td>
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<td>browning and fruit quality of ‘Rosy Glow’ (E Crouch)</td>
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PUBLICATIONS

Scientific journal papers

L. Butler, 2015. Internal flesh browning of ‘Cripps’ Pink’ apple (Malus domestica Borkh.) as influenced by pre-harvest factors and the evaluation of near infrared reflectance spectroscopy as a non-destructive method for detecting browning. (MSc)

T. J. Majoni, 2011. Physiology and biochemistry of ‘Cripps Pink’ apple ripening and disorders with special reference to post-harvest flesh browning. (MSc)


Scientific conference proceedings


Making the desert bloom

A column by Wiehann Steyn
Making the desert bloom

A group of nine South Africans visited Israel on their way to the 30th International Horticultural Symposium in Istanbul, here's what they learned about the Israelis' irrigation practices.
Nine South African water pilgrims on their way to Istanbul, took a detour to Israel to learn more about the nation’s irrigation practices.

While these fruit industry representatives, including myself, Hugh Campbell and Xolani Siboza of Hortgro, Karen Theron of Stellenbosch University, Hannes Halgryn, Keith Bradley and Angelique Zeelie of Fruitways, Tobie van Rooyen of ProCrop, and Abie Vorster of Netafim, were on our way to the 30th International Horticultural Symposium held in Istanbul from 12 to 16 August we couldn't pass up the chance to learn from this water scarce Mediterranean country.

We hoped to learn more about the exemplary management of water, precision irrigation and irrigation innovation for which the Israelis are so well known. Along the way, we also visited pome and stone fruit orchards, low chill breeding programmes and horticultural scientists. Here follows a list of the key take home messages around the water issues stemming from the visit:

1. Water should be managed as a commodity that has value. When water has to be bought and can be sold, people are more likely to treat it as a resource from which the maximum value should be extracted. This ensures efficient water use at national, municipal, farm and household level—Prof Eilon Adar, Head of the Zuckerberg Water Research Institute, Ben Gurion University in the Negev desert.

2. Underground water is connected and boreholes should be coordinated at catchment level—Prof Eilon Adar. We need a bottom-up approach for ground water management at local catchment level.

3. While it is important to optimise water use and to save water, we need to secure more water for the future, for example by recycling of water. 80% of municipal water in Israel is recycled and sold to agriculture.

4. Recycled water is an untapped resource in South Africa. Their might be opportunities for agricultural communities surrounding rural towns to invest in recycling and to thereby secure another source of irrigation water whilst helping the municipality to manage sewage.

5. I only saw drip wherever we went in Israel. Israeli summer conditions are similar to ours, although the humidity seems to be higher. Drip irrigation undoubtedly requires more intensive management, but we surely should be able to make it work anywhere in our industry, in fact, we may need to make it work...

6. Israel accepted its water limitations but had the dream of “making the desert bloom”. The current drought in the Western and Eastern Cape is a wakeup call that we require the same urgency to deal with our new and future reality of water limitation. The believe that “everything will be ok in the end” or that “they” (whoever that me be) should sort out our water problems is misplaced and unrealistic.

7. Midday stem water potential is commonly used in Israel to irrigate according to the plant’s needs—Prof Amos Naor of the Migal Galilee research institute. It makes a lot of sense to measure the patient’s vital statistics rather than assessing his health from the condition of his shoes. The new continuous logging stem water potential probes developed by Saturas is an exciting development that may have us determine plant water needs and irrigate according to plant water status rather than indirectly through assessing soil water status. FQ
Apples under nets, Golan Heights.

‘Golden Delicious’ apples on Golan Heights.

Apple orchards on Golan Heights with Syria in background.

PHOTOS PROVIDED BY WIEHANN STEYN.