Introduction

Grain contamination by round and conical snails poses a serious threat to grain exports. Snails also cause damage to emerging crops and can clog machinery at harvest resulting in delays and frustration.

Controlling snail populations is vital if grain contamination and crop damage are to be prevented. This means monitoring and managing snails regularly throughout the year, see Figure 1.

Research has shown that successful snail control requires knowledge of the snail behaviour, the type, size and numbers of snails present, and the application of physical and chemical control techniques.

This management manual brings together the results of over fifteen years research and a million dollars of investment by the Grain Research and Development Corporation (GRDC), The South Australian Grains Industry Trust (SAGIT) and other organisations including the Wool Research and Development Corporation. In addition to presenting research findings as useful management information, this manual aims to introduce the diverse range of people involved in the portfolio of snail research projects and to share their experience.

Many research organisations, researchers, agronomists and farmers have been involved in these projects. Recognition must go to the 27 farmers and the PIRSA Rural Solutions consultants who participated in a three year on-farm monitoring study. Their work expanded the data collection area to several hundred hectares located across South Australia farmed under a range of systems and rotations.

Snail research supported by grain growers and the State and Federal Governments

Funding body	Project Id. no.	Title	Organisation
GRDC	ACC1	Optimising on farm snail management	Agricultural Consulting Co
GRDC	AMC9	Report on the impact of snails in the southern region	Allan Mayfield Consulting
GRDC	CSE775R, CSE 15 & CSE109	Biological control of Mediterranean snails in southern Australia	CSIRO Entomology
GRDC	DAS300	Integrated snail management in the southern region	SA Research & Development Institute, University of Adelaide
SAGIT	S299	Integrated snail management in the southern region	SA Research & Development Institute
GRDC	DAV469	Mediterranean snail survey Victoria and New South Wales	Dept of Natural Resources & Environment Victoria
GRDC	JLC30	Snail communication strategy	Jon Lamb Communications
GRDC	SYP1	Harvest technology for quality grains	SYP Alkaline Soils Group
GRDC	UA418	Nematodes as bio-control agents of helicid snails	University of Adelaide
GRDC	USA28	Post harvest solutions for quality grain	University of South Australia

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Thanks must go to all the farmers and advisors who participated in many of the snail research projects and to all the commercial companies who gave their support with both time and resources.

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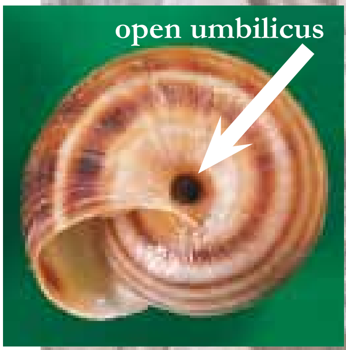
Snail facts

In Australia four species of introduced snails are pests of grain crops and pastures in the Southern Region. These can be divided into two distinct groups: round or white snails and conical or pointed snails.

Vineyard or common white snail



Scientific name *Cernuella virgata*

Geographic location
Found throughout the agricultural districts of SA, the Victorian Mallee and Wimmera. Also occurs in WA, NSW and eastern Tasmania.

Features
Mature shell diameter between 10-20mm.

Coiled white shell with or without a brown band around the spiral. Open, circular umbilicus. Under magnification regular straight scratches/etchings can be seen across the shell.

Food source
Dead organic material but can severely damage young cereals, canola and pulse crops.

Importance and behaviour over summer
Contaminant of grain. Over summers off ground on plants, stubbles, posts etc.

White Italian snail

Scientific name *Theba pisana*

Geographic location
Common along the coastal areas of SA. Also occurs in coastal areas of NSW, Victoria, WA and eastern Tasmania.

Features
Mature shell diameter between 10-30mm.

Mature snails have coiled white shell with broken brown bands running around the spiral. Some individuals lack the banding and are white.

Semi-circular or partly closed umbilicus. Under magnification cross hatched scratches can be seen on the shell.

Food source
Green plant material and dead organic material. Can cause significant damage to emerging crops and pastures.

Importance and behaviour over summer
Contaminant of grain. Over summers off ground on plants, stubbles, posts etc. Especially found in green weeds.

Conical or pointed snail

Scientific name *Cochlicella acuta*

Geographic location
Highest numbers found on Yorke Peninsula in SA. Isolated populations also found in other parts of SA, Victoria, NSW & WA.

Features
Fawn, grey or brown in colour. Mature snails have a shell length of up to 18mm. The ratio of the shell length to its diameter at the base is always greater than two.

Food source
Dead organic material. Never recorded feeding on crops or pastures.

Importance and behaviour over summer
Contaminant of grain. Over summers under stones and stumps, as well as on fence posts and vegetation.

Small conical or pointed snail

Scientific name *Cochlicella barbara*

Geographic location
Occurs throughout SA, but is most abundant in the higher rainfall areas (>500mm). Also widely spread in NSW, Victoria and WA.

Features
Fawn, grey or brown in colour. Mature shell size of 8-10mm. The ratio of its shell length to its diameter at the base is always two or less.

Food source
Green plant material and dead organic material. Recorded as a pest of lucerne.

Importance and behaviour over summer
Has caused grain contamination in the lower South East of SA. Often over summers in leaf litter at the soil surface or just below surface and under stones and stumps etc., but can be found on posts and vegitation.

Reproduction

These four species of snails are hermaphrodites. Each snail has both male and female reproductive organs enabling each snail to lay egg clusters after mating.

Snails lay many hundred eggs in a season and in favourable conditions can multiply rapidly. It is estimated that in the field each snail lays about 400 eggs a year (see Figure 2). This varies with species and seasonal conditions. **Controlling snails before or soon after egg laying commences is essential.**

The start of egg laying is determined by soil moisture. In trials where soil was kept permanently dry no eggs were deposited.

A light rainfall of about 1-2mm (4-8 points) in late summer may cause snails to descend to the soil from stubble and fence posts etc.

If conditions stay cool and moist snails may stay down and feed. Mating appears to be triggered by the first major autumn rain when the soil has reached near field capacity or by continuous cool moist weather in autumn. Egg laying will occur providing soil remains moist.

Egg laying usually commences in April and finishes by September but this timing varies between regions and seasons. Egg laying does not occur in summer even after a significant rainfall event as the reproductive organs of the snails are not mature at this time of the year.

Eggs are laid in clusters with each cluster consisting of between 20-80 milky white eggs for round snails. Laboratory work shows that conical snails produce less egg per cluster, often only about half the number found in the egg clusters of round snails.

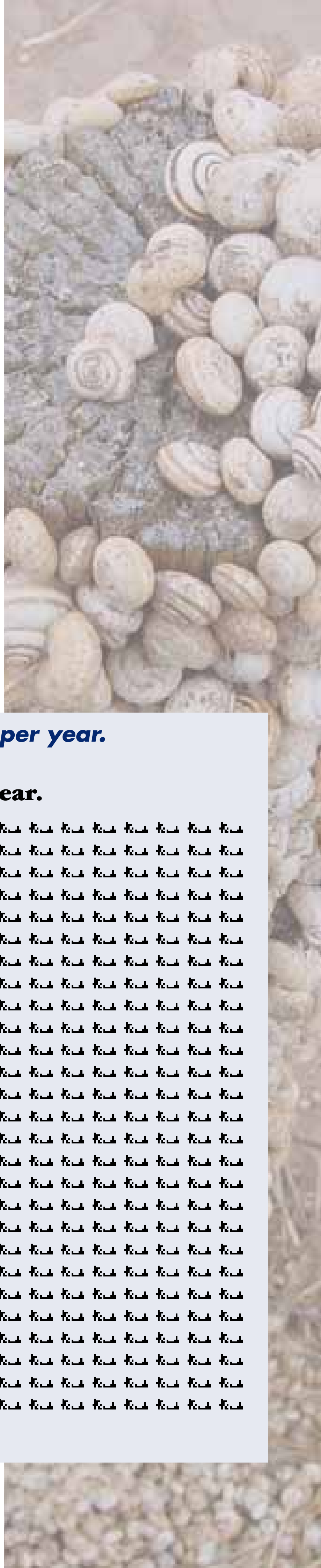
An individual snail can lay several egg clusters in a season. In the laboratory egg clusters produced later in the breeding season usually contain less eggs. Eggs are laid near the soil surface.

To monitor for egg laying, look at the soil surface early in the morning when snails can be found with their foot (the fleshy snail body) inserted in the topsoil. The eggs are laid in shallow holes excavated by the snail.

Eggs hatch after about two weeks and round snail hatchlings are up to 1.5mm in diameter. Conical hatchlings are smaller, at about 1mm in diameter, but may be found in groups.

Figure 2: Reproduction – Each snail lays about 400 eggs per year.

1 +1 = approximately 800 juveniles snails in a year.



Pestering snails in Europe and Australia

CSIRO Entomologist Dr Geoff Baker's interest in the snails began whilst based in Portugal searching for biological control agents for millipedes. Knowing the snails were introduced pests back in Australia his interest was aroused when he observed a variety of invertebrates attacking them in their native Mediterranean habitats.

Geoff's initial work in Australia started in 1984 and focused on understanding the basic biology of white and conical snails, how their population numbers varied in space and time and the environmental factors driving these variations. Much of his work centered on the dispersal capacity of white snails. He then led a six year program in Mediterranean Europe searching further for potential biological control agents for use in Australia.

Much of Geoff's ecological work now underpins the practical and solution based research that has been carried out more recently.

Geoff now leads CSIRO's Cotton Pest Management research, but he continues to contribute across a range of snail research issues including ecological, behavioral and biological control aspects.

Snails and moisture

A light 1-2mm shower is enough to trigger snail activity in late summer/early autumn. Snails remain active provided conditions remain cool and moist but become inactive if warm or hot conditions re-occur.

A series of heavy dews can also trigger snail activity in autumn.

About two to three consecutive days of cool moist conditions are required for a high level of mortality to be achieved from baiting.

Rainfall in the current year impacts on spring populations in that year and on autumn populations in the following year.

A rain shower of 5mm or more early in the harvest period is enough to cause snails to crawl down the crop stems but a similar rainfall event later in harvest often causes little movement.

Distribution and movement

Since their introduction to Australia from Europe in the early 1900's, round and conical snails have continued to spread across southern Australia.

Where and when snails were first recorded in South Australia:

Common white snails	Millicent, 1920-21
Small conical/pointed snail	Mt Gambier, 1921
White Italian snail	Port Adelaide, 1928
Conical/pointed snail	Minlaton, 1953

Why snail numbers have rapidly increased in southern Australia is not well understood. The adoption of conservation farming where there is stubble retention, less burning and less tillage are factors which may have resulted in increased snail populations, especially in the calcareous and highly alkaline soils. Consecutive seasons of above average winter and spring rainfall may also have contributed. **Early identification of population growth is essential for rapid control. The importance of monitoring cannot be over emphasized.**

Snails have been found along all major transport routes between South and Western Australia, especially in camping grounds and at intersections along these roads. This suggests snails have become proficient hitch-hikers and are moving between regions on transport.

To avoid moving snails from infested to clean areas farm machinery and produce such as hay should be inspected and if necessary cleaned of snails.

How fast can snails move? 60km/hr in a built up area and 100km/hr on the freeway!

In Victoria snails are found in the Mallee and northern Wimmera districts. Common white and small conical snails are the species most frequently seen, with high concentrations found near silos and railways. In Victoria snails are seen to prefer areas with an average rainfall of 300-450mm per year and high pH and calcareous soils, but are not found on all high pH and calcareous soils. The small pointed snail shows an affinity to irrigated land and around lakes.

Snails are not isolated to the cropping districts but are found all the way along the coast between SA and Melbourne.

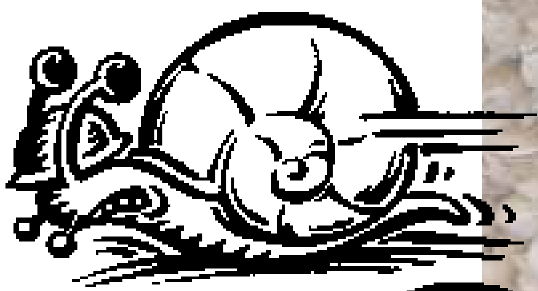
In a recent roadside survey, round and conical snails were not identified in grain growing areas of southern New South Wales.

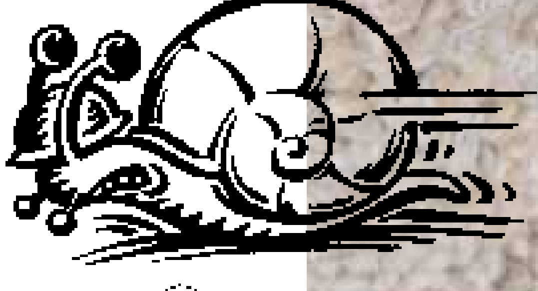
During the winter and spring individual snails have been recorded to move up to 30m over a seven day period.

Movement appears to be directional, ie in a day the majority of snails move in the same direction. A range of cues for direction of movement has been tested but a directional trigger has yet to be found. Factors that have been investigated include crop type, crop damage, food, soil properties, moisture, temperature and wind direction.

A fence post encrusted with 30cm of snails equates to about 4000 round snails. When mature the snails, from just one post, could produce over one million juvenile snails. Use early and fenceline baiting to control snails before egg laying.

Resting before causing a population explosion!





Don't turn your back on snails they may be creeping up on you!

Ecology knowledge provides better control

PhD student Vanessa Cavagnaro is sponsored by GRDC to research the ecology of Mediterranean snails in crops in southern Australia.

Vanessa's work has brought her in close contact with farmers and agronomists enabling her to share her ongoing research findings on issues such as snail movement and reproduction.

"The project has provided me with the opportunity to be part of an important research and extension group whoose aim is to better manage and control an important agricultural pest."

"I have gained many new skills and consider my discussions with farmers and other researchers as particularly beneficial."

A key part of Vanessa's work is the development of simulation models which use her research findings and when completed will hopefully provide key steps in the development of optimal control measures for snails in grain crops in the Southern Region.

Vanessa submits her thesis in 2003.

Integrating control wi

From a management point of view the lifecycle of the four types of snail is very similar and can be divided into seven main phases. Applying the appropriate management at each phase in the lifecycle is vital for successful snail control.

Aestivation

- prolonged periods of dryness and high temperatures trigger aestivation in late spring/early summer
- snails move up stubble, fenceposts and vegitation to rest above ground to avoid water loss during summer
- summer rains can trigger short periods of activity but no breeding occurs over summer

Movement

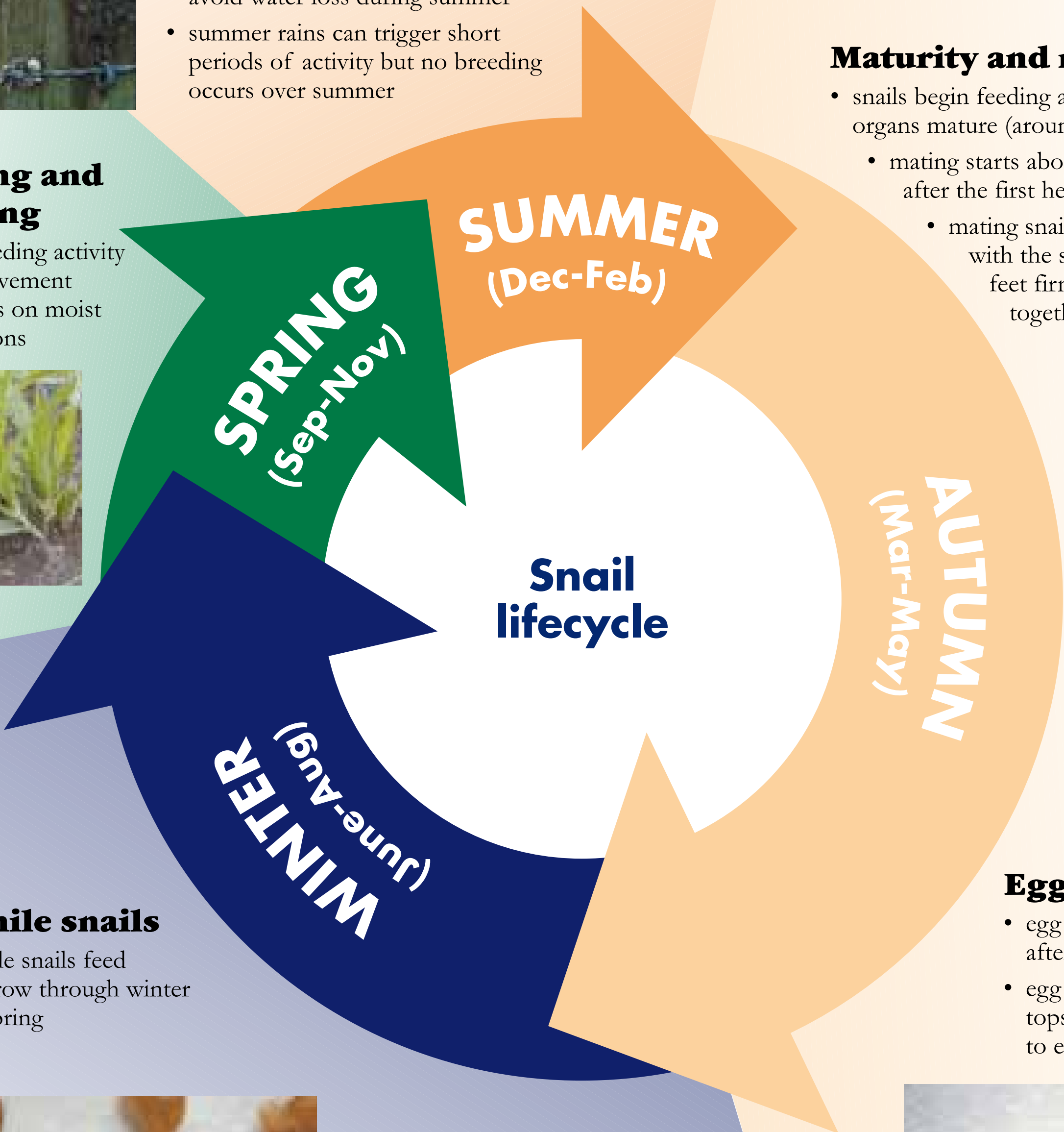
- rainfall and cool moist conditions trigger snail activity
- a 1-2mm shower is enough to trigger activity

Maturity and mating

- snails begin feeding and reproductive organs mature (around March/April)
- mating starts about 2-3 weeks after the first heavy autumn rain
- mating snails are found in pairs with the soles of their feet firmly pressed together

Feeding and growing

- snail feeding activity and movement depends on moist conditions



Egg laying

- egg laying begins shortly after mating
- egg clusters are laid in topsoil from late autumn to early spring

Juvenile snails

- juvenile snails feed and grow through winter and spring

Hatching

- hatchlings emerge from eggs about two weeks after they are laid

ith the snail's lifecycle

All year round management of snails is required for control of large snail populations.

Population details should be recorded before and seven days after control measures are applied.

Applying controls before or shortly after breeding commences is essential to minimise increases in populations.

Bash 'Em

Stubble management
Rolling
Cabling
Slashing
Grazing

Burn 'Em

Stubble management
Burning

Grain cleaning

Bait 'Em

Early baiting to kill snails before egg laying

Windrowing

Tillage

Causes some mortality of eggs and snails

Modify header

Before harvest

Bait 'Em

Broadacre, border and fenceline baiting

Attacking snails on all fronts

Leader of the SARDI Entomology team, Dennis Hopkins, has been chasing snails since 1983. However, he believes the recent focused research effort supported by GRDC, SAGIT, SARDI, grain growers and industry has enabled real progress in snail control to be achieved.

Dennis's work has focused on in-field control especially burning and baiting as well as on biocontrol for snails.

"Initially we thought that baiting in late winter was the best option, but with new knowledge about round and conical snails we now know that early baiting in moist conditions in autumn is a key to successful snail management."

Dennis plays an important role in coordinating many of the recent and on-going research projects on in-paddock control options and on the parasitic fly.

"Our knowledge of snails and their control is still incomplete but we have made excellent progress in recent years and have now developed systems of integrated snail control based on solid research findings."

Monitor, monitor, monitor

The importance of monitoring snails cannot be over emphasised.

Knowledge of the type of snails present (round or conical), the number of each type and the sizes present is necessary before the appropriate management decision can be made.

Monitoring can help target control to areas of high snail density.

Counting snails seven days after controls have been applied provides an indication of success or otherwise.

Snail monitoring should be part of all grain growers' routine checks. Early detection and control of new infestations can help delay the widespread establishment of snails.

The use of a quadrat, sieve boxes and the snail recording sheet (see Figure 3) helps simplify monitoring.

Remember, it is only necessary to count live snails as these can reproduce, cause crop damage and move into the mature grain. The body of a live snail is visible and withdraws into the shell when poked. During dry conditions and the summer live snails close the shell opening with a layer of mucus and calcium.

The number of snails per square metre is the recognised measurement for snails.

Taking counts in representative areas across the whole paddock is important (see Where to sample).

When monitoring for snails note where they occur in the paddock. If snails are restricted to certain areas control measures can be focussed there.

Key monitoring times

- January/February - to assess options for stubble management
- March/April - to assess options for burning and/or baiting
- May to August - to assess options for baiting, particularly along fencelines
- 3 to 4 weeks before harvest - to assess need for header modifications.

Counts should be taken before control operations and seven days after control to record effectiveness.

Paddock sampling for snails

How to sample

To sample snails, use a 0.1 m^2 (32cm x 32 cm, approximately a square foot) quadrat. Place the quadrat on the ground and count all live snails within it. If two snail groups are present (round and conicals), record the number of each group separately (see Fig 3). To determine the split of snails present by size place all live round snail found within the 0.1m^2 quadrat into a sieve box, shake gently and they will separate into two sizes – 7mm and larger and smaller than 7mm.

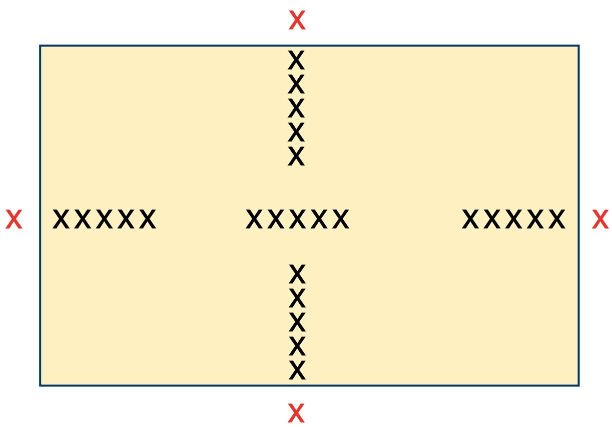
Round snails less than 7mm in diameter and conicals less than 7mm in length are unlikely to be controlled with baits. The length of conical snails is best determined by measuring. Draw a 7mm line on your recording sheet as a quick guide.

Sieve boxes are a quick way of separating different sized round snails. These can be constructed from two stackable containers eg sandwich boxes. The bottom is removed from one and replaced by punch hole screens. Suggested screen size is 7mm round or hexagonal.

Where to sample

Five sampling transects should be taken in each paddock. One transect is taken at 90 degrees to each fenceline whilst the fifth transect runs across the centre of the paddock. Take five samples (counts), 10 metres apart along each transect. Record the size and number of the snails in each sample.

Average the counts for each transect and multiple this figure by 10 to calculate the number of snails per square metre in that area of the paddock.



X - *Paddock sampling areas*
X - *Make observation of snail abundance in these areas. Is there potential for reinvasion?*

Is there potential for reinvasion?

Observe habitats and snail numbers outside the paddock being monitored to determine if there is potential for reinvasion. Adjacent roadside verges, stone heaps, pasture paddocks and heavily infested crops are often the source of invading snails. Local regulations for snail control on roadsides and in native vegetation should be consulted.

Figure 3: Snail monitoring sheet – The following information should be recorded for each paddock before and seven days after control treatments. The number of snails/m^2 should be compared with the thresholds outlined in 'Control options'.

Paddock name	Sampling date	Count: before or after treatment	Crop
Back South	17th May 2002	Before - baiting	Canola

	White snails		Conical snails	
Transect 1	**< 7mm diameter**	**>7mm diameter**	**< 7mm length**	**>7mm length**
1	50	15	80	12
2	32	12	45	16
3	18	6	62	28
4	46	28	110	33
5	81	34	59	18
Total	227	95	356	107
Average	45.4	19	71.2	21.4
Snails/m^2	**454/m^2**	**190/m^2**	**712/m^2**	**214/m^2**
	White snails		**Conical snails**	
Transect 2	**< 7mm diameter**	**>7mm diameter**	**< 7mm length**	**>7mm length**
1	63	36	42	17
2	58	26	80	25

Conical snail ruler |—| 7mm

See inside back cover for a complete monitoring sheet.

Feeding damage

Monitoring at early growth stages may identify snail feeding damage. baiting is the only control method availabe at this growth stage

Snail feeding damage in cereals

Snail feeding damage in canola

Control options

Bash 'Em – Stubble management

Control option	When	Which snails	Thresholds	Effectiveness
Cabling Rolling Slashing	Hot sunny days, over 35°C, in summer, post harvest. Ideally, several hot days should follow.	Round and conical. Often better for round as conicals hide under rocks.	Round snails - in cereals - 20/m^2. Pulses and canola 5/m^2 at seeding. Conical snails - no thresholds established.	50-90% kill when conditions are 35°C+. Less effective in dense cereal stubbles.

Snails aestivate over summer on any object they can find above the soil surface. This can be upright stalks of stubble and weeds, fence posts, under troughs and even tree trunks. By moving off the ground the snails escape searing summer soil temperatures. Conical snails not only go up but also go down resting under the shade of rocks and vegetation including summer weeds.

The objective of stubble management is to knock snails onto the hot soil surface. The snails seek out new off-ground sites; as they travel across the hot ground they burn-up food reserves. The heat also causes snails to produce mucus which leads to water loss. If this loss is severe, snails will die of desiccation. The hotter the soil surface the greater the likelihood of the dislodged snails starving or desiccating and dying.

Green summer weeds and rocks protect snails from being bashed to the ground. Summer weeds should be sprayed and browned-off before stubble is bashed to remove these cool moist microclimates and food sources. Cabling will roll stones over and is the most effective snail treatment in stony paddocks, especially if conical snails are a problem.

Stubble management is generally a cheap and environmentally friendly method of killing snails before the breeding season. It is likely to be less effective if there is a dense cover of organic matter which insulates the soil surface.

The potential for erosion should be balanced against the value of killing snails before embarking on stubble bashing.

Keys to success

- Bash stubble when air temperatures are above 35°C
- Repeated operations are more effective in coastal regions
- Start stubble management mid morning when the soil surface has heated
- Kill summer weeds before bashing stubble
- All upright plant material must be flattened by the bashing operation
- Use stubble bashing as part of an integrated control strategy.

Rolling

Rubber tyre or steel ribbed rollers can be used to flatten the stubble, removing above-ground resting sites and squashing some snails. Rubber tyre rollers allow a greater width to be rolled in one pass. About 10ha/hour can be rolled with an 8m roller. One pass is generally sufficient to flatten wheat stubble but two passes, in opposite directions, are often used to snap the more 'springy' barley stubble. If some upright stubble remains after rolling the effectiveness of the rolling will be reduced. Trials have shown that rolling can cause 50 to 90% snail mortality. In soils prone to erosion steel ribbed rollers reduce the likelihood of soil erosion.

Slashing

Slashing flicks snails to the ground, removes all tall stubble and effectively crushes some snails. The dislodged snails may climb back onto the short stubble that remains reducing effectiveness of slashing. About 4ha/hour can be slashed with a 4m slasher. This is relatively slow due to the narrow width covered at each pass. Trials have shown slashing can cause 50 to 90% mortality of snails. In stony paddocks care must be taken to avoid sparking a fire.

Cabling

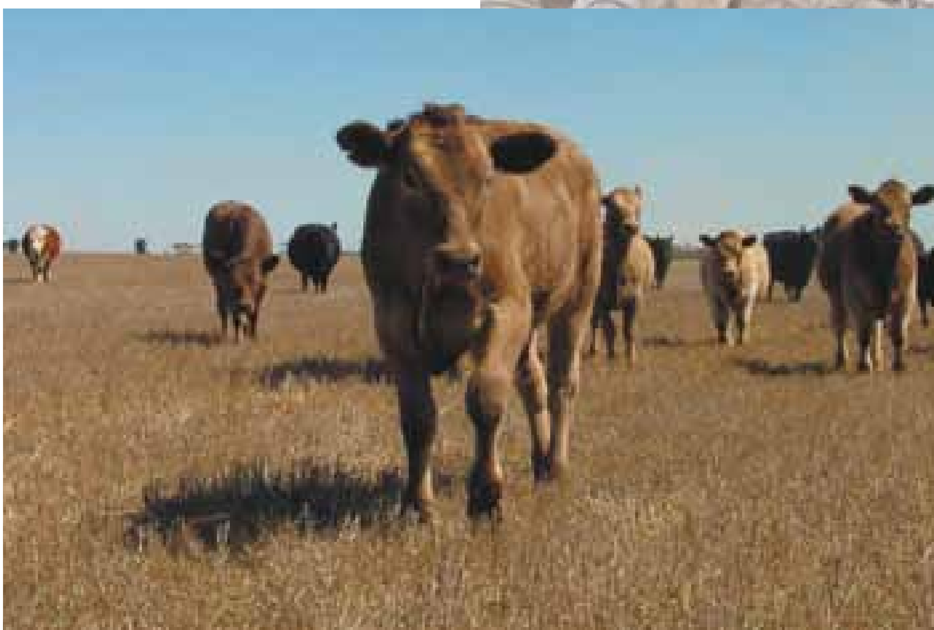
Cabling is carried out using a 3-5cm diameter cable, often an old punt cable, strung between two tractors or utes which are driven up to 300m apart. Some farmers have also used a 20-25mm chain which tends to be more aggressive and expensive but a chain results in more rocks being rolled over. At each end of the cable a short length of quarter inch chain should be inserted to act as a safety breaking point. Radio or telephone communication between the vehicles is essential.

Cabling is extremely fast, about 120 hectares can be covered by a 150m cable in one hour. The speed of operation makes repeating the process, even on the same day, possible. This makes cabling especially popular in areas where soil and air temperatures over summer are insufficient to achieve reliable snail control with rolling or slashing.

Cabling is becoming a popular method of removing snails from stubble and in trials led to reductions in snail numbers of up to 70%, after one pass. Cabling is rather more aggressive than rubber tyre rolling and results in snails being knocked from their resting sites, as well as laying much of the stubble flat. Rocks are also turned over by cabling, exposing conical snails to the heat. Cabling stony paddocks immediately prior to burning exposes more snails to the fire resulting in a better kill.

Cabling, especially with a chain can cause plant material to be pulled out by the roots leaving soils susceptible to erosion. Care is needed where there are obstacles such as trees or stone heaps in the paddock. The fire risk with cabling is minimal except in paddocks with iron stone rocks or when cables are moved near steel posts, stobie poles etc.

Grazing



Grazing animals knock snails from stubble and may also trample or accidentally consume them when grazing. Results from grazing are variable as dislodgement is dependent on stock movement. A 32% reduction in snails was recorded on a grazed lentil stubble. Generally, grazing is considered to be less effective than rolling, slashing or cabling but can still be considered in an integrated snail management program.

Burn 'Em – Stubble management

Control option	When	Which snails	Thresholds	Effectiveness
Burning	After the burning season opens to the opening rain. Most effective early in the burning season.	Round and conical. Less effective on conicals if rocks are not turned.	Round snails - in cereals - 20/m^2. Pulses and canola 5/m^2 at seeding. Conical snails - no thresholds established.	Even burn 80-100% kill. Patchy burn 50-80% kill.

Burning remains the most effective method of pre-breeding snail control. Research has found that an even burn is important for good snail control. This is because only a poor kill is achieved in the unburnt patches (see Figure 4).

For good snail control the aim is to achieve an even burn across the whole paddock.

Snails harbour under rocks and summer weeds. Rocks should be turned immediately before burning by cabling or fire harrowing. Summer weeds should be desiccated and browned-off before a burn (see Figure 5).

Burning stubble has other positive and negative impacts. It can destroy stubble born diseases and weed seeds, but burning reduces organic matter and can kill soil organisms, both of which are detrimental to the soil and crop production. Burning must be avoided on soils which are prone to erosion. All these factors need to be considered before burning.

Where snail populations are large a strategic burn, perhaps only once every three or four years, will dramatically increase the success of managing snail numbers with baits.

Figure 4: Excellent round and conical snail control is possible with an even burn across the whole paddock

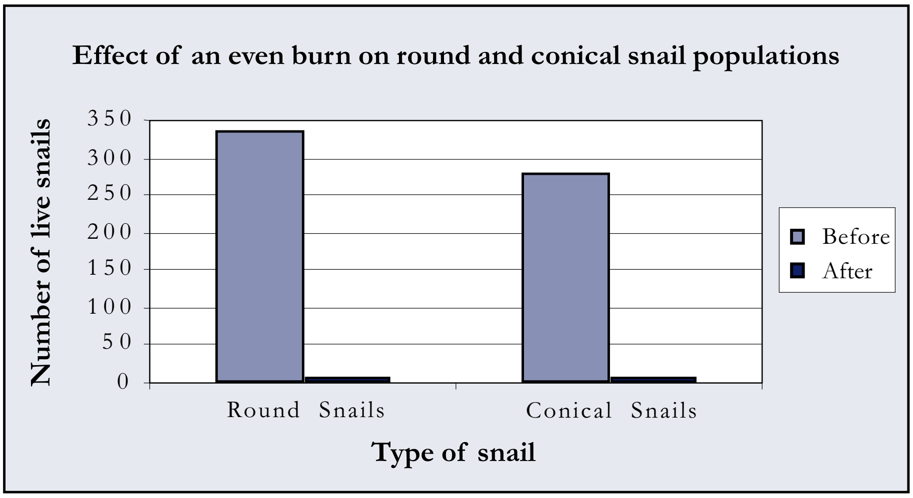
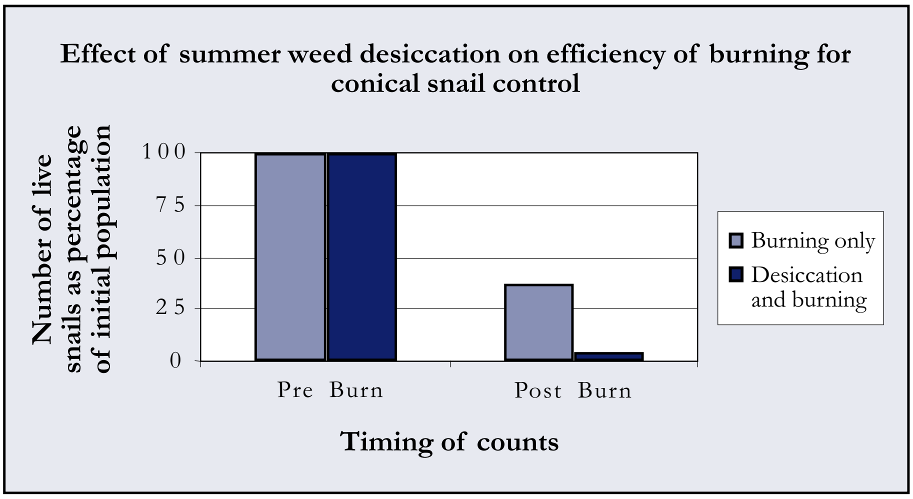


Figure 5: Desiccation of summer weeds prior to burning substantially increases snail kill, the graph illustrates the benefit for control of conical snails



Keys to success

- Desiccate summer weeds before burning, especially for later burns
- Disturb rocks sheltering snails - cabling just prior to burning or fire harrowing are likely to improve control
- Ensure the most thorough burn possible
- Use burning as part of an integrated control strategy, eg follow by in season baiting etc.

Summer weed control and snail management

- The presence of green summer weeds may reduce the effectiveness of fire in controlling snails. Up to 40% snail survival can occur where green weed material protects snails from fire
- A combination of desiccating summer weeds and fire can reduce round and conical snail numbers by as much as 95%
- Similarly a combination of weed desiccation and a stubble management operation (eg cabling or rolling) is likely to increase the level of snail control.

Spreading the word on snail control

Agronomist Dr Allan Mayfield has many farmer clients who have had to learn to manage snails; and they have turned to him for assistance. This need for information led Allan to collaborate with Bill Long on many of the applied research projects. These include the work on tillage, summer weeds and windrowing.

As trials manager for the Hart Field Site, chairman of the GRDC Annual Updates and the Grain Legume Handbook committees and Director of the Farm Management 500, Allan has been able to ensure the latest information about snail control has been communicated.

Bait 'Em

Control option	When	Which snails	Thresholds	Effectiveness
Whole paddock, border and fenceline baiting.	Start when rain/ moisture triggers snail activity in autumn and before significant egg laying. Finish late August or two months prior to harvest.	Target mature snails - round snails larger than 7mm diameter and conicals larger than 7mm length. Baits largely ineffective against juvenile snails.	Round snails - in cereals - 20/m^2. Pulses and canola 5/m^2 at seeding. Conical snails - no thresholds established.	60-90% kill for round snails. About 50-70% kill for conical snails. Dependant on timing, snail activity and bait rate.

Plan and avoid panic reactions to snails

Yorke Peninsula agronomist Trevor Dillon has been tackling snails for longer than he wishes to remember. Since the mid 1970's he has been observing snails and sharing information and understanding with scientists and farmers.

"If there is one message I would like farmers to remember when it comes to snails it is to monitor and be proactive."

"We don't want panic reactions with most of the farm burnt in a single year in a desperate attempt to control escalating snail populations."

Although Trevor would prefer to see zero burning, he acknowledges there is a place for a 100% hot burn once in a while, if snails are present. If the farm has snails he suggests growers only burn the two or three wheat stubbles with the highest snail numbers. This of course is only in situations where there is no risk of soil erosion.

Trevor brought many years experience to the research projects and has played a major role in developing collaborations between farmers and researchers.

The benefits of stubble management can be lost if baiting is not used to further reduce snail numbers. **Baits are not registered for use in pastures** so all baiting should be focussed in cropping paddocks. Stock must not be grazed on stubbles which have been baited.

Egg laying does not occur over summer but snails mature rapidly following significant rains or regular dews in autumn. Killing mature snails before autumn egg laying significantly reduces the potential for populations to build up that season.

Research shows that mature snails are the most likely to take bait especially in autumn. Round snails less than 7mm in diameter and conicals less than 7mm in length, which are usually present from late winter onwards, are unlikely to be controlled with baits.

Baiting rates are based on the number of round snails present which are 7mm or greater in diameter (see Table 1).

Snail numbers should be monitored to assess the need to bait and to determine the bait rate to use (see Page 10). Seven days after baiting a second count should be taken to identify the effectiveness of the control and determine the need for further bait applications.

Based on these counts, baiting can be confined to areas of high snail density, for example the fenceline or the crop perimeter/border.

Growers should monitor through the growing season to check for reinvasion. Multiple bait applications may be required during the winter and early spring but this need must be based on monitoring results.

All baiting must be stopped by the end of August or two months before harvest to ensure bait has broken down and does not become a contaminant of grain. Windrowed crops should not be baited.
There is zero tolerance for bait contamination of grain.

Fenceline and border baiting

Fence posts and roadside vegetation etc are popular sites for aestivating snails. This makes the area adjacent to the fence a 'high traffic area' for snails following the autumn rains. Repeated baiting in these areas can result in a high level of snail mortality.

For fenceline treatments, it may be necessary to increase the rate of bait to 10 kg/ha especially if the snail invasion pressure is high. Repeated baiting may be required but this must be based on monitoring counts. Fenceline bait is generally applied with a small bait spreader or is scattered manually. Border baiting which covers a 30-50m strip around the edge of the paddock and crop is spread mechanically.

5kg/ha of bait equates to four baits/m^2 for large pellets (5mm diameter) and 12 baits/m^2 for smaller pellets (2mm diameter).

Broadacre baiting

Where snails are present right across a paddock , apply 5-10kg of bait per hectare using a specialised ute mounted bait spreader, fertiliser spinner or by a plane. The rate is determined by snail density (see Table 3). With ground equipment, about 60 hectares can be spread with 5kg/ha of bait in an hour.

When to bait

Baiting should commence following an autumn rain and when there is sufficient moisture for snails to remain active for two to three days following the bait application. Heavy overnight dews often provide sufficient moisture for snails to remain active and move to baits. Bait degrades in UV-light so it should be spread immediately before or just after there is enough moisture over the two to three days to stimulate snail movement.

Bait rates

For all bait pellets currently available the standard rate for snail control in cereal, pulse and oilseed crops is 5kg of bait per hectare. Research has identified that if there are more than 80 round snails (> 7mm in diameter) per square metre this rate should be increased to 8 to 10kg/ha (see Table 3).

For conical snails, repeat applications of the 5kg/ha rate are probably more efficient than a one-off 10kg/ha.

Emerging canola is especially susceptible to damage and these crops should be closely monitored for snail damage and the need for baiting.

Truly integrated research

Dr Suzanne Charwat brought a new level of enthusiasm and farmer involvement to snail research when she was appointed to lead the integrated snail management research for SARDI in 1999.

Prior to this she worked on the GRDC/RIRDC project on biocontrol of snails with nematodes.

"The snail project is truly one of the most multi-faceted projects I have been involved with.

"True to the aim of developing an integrated approach to snail control we had three major outcomes during my time with the project."

Firstly, with farmer involvement Suzanne and her colleagues achieved state-wide snail monitoring and from this determined the effectiveness of existing and new mechanical control methods and fine-tuned their application times.

Secondly, her work laid the foundation for a new baiting strategy based on a better understanding of the interaction of snail population dynamics and the timing of bait applications.

Thirdly, the first field releases of the biocontrol agent presented farmers with an important ally in their battle against conical snails.

"The progress we made during these two years was by and large due to the enormous dedication and enthusiasm of all co-workers, consultants and farmers involved."

In addition to producing key advances in snail management Suzanne spoke to many farmer meetings and produced practical guidelines for snail management.

Suzanne returned to her native Germany in 2001 and her contribution to snail research and communicating this information is appreciatively remembered by farmers across the Southern Region.

Table 1: Recommended bait rates for cereals, pulses and oilseeds

Snail	Snails/m^2 over 7mm	Kg bait required/ha
Round snails	Less than 80/m^2	5kg/ha
	Over 80/m^2	8-10kg/ha
Conical snails	No threshold established	5kg/ha

Which snail bait?

At the time of publication about ten snail baits are commercially available in Australia. These are retailed under different brand names but contain one of three active ingredients: metaldehyde, methiocarb and Fe-EDTA, (see Table 2). Each of these products has been used either in trials or by the farmers involved with the three year monitoring study.

No significant differences in kill have been observed between the three active ingredients.

Currently choice of bait comes down to which products are registered for use in your State and price. Always consult the label before application.

Table 2: Snail baits commonly used in Australian agriculture or horticulture

Active ingredient	Mode of action
15g/kg metaldehyde	Irritant which causes excess mucus secretion and desiccation; inhibition of mobility; nerve poison at high concentrations.
20g/kg methiocarb	Inhibits nervous system
60g/kg Fe-EDTA	Stomach poison

Keys to success

- Determine number of live snails/m^2 before baiting
- Bait early before egg laying commences
- Two or three bait applications may be required in a season
- Based on monitoring, bait fencelines throughout the season to combat reinvasion of snails into the edges of paddocks
- For round snails increase rate of bait if snail numbers are above 80/m^2 (snails>7mm)
- Spread bait when moist conditions are forecast for 2-3 days after application
- Monitor baited areas to determine need for further bait application
- Use baiting as part of an integrated management strategy.

Biological control

A range of biological controls for round and conical snails have been investigated but only one species is cleared for release in Australia; that is the parasitic fly *Sarcophaga penicillata* which targets the conical/pointed snail *Cochlicella acuta*.

Research into the release and establishment of this fly is ongoing. During 2001, 2002 and 2003, flies have been released at 20 sites on Yorke Peninsula with establishment being recorded at 5 sites so far.

Life cycle of the parasitic fly *S. penicillata*

Over ten years ago *S. penicillata* was first identified as a potential biological control agent for the conical snail, *Cochlicella acuta*. The flies are native to Europe where they were found to parasitize aestivating conical snails.

During the summer *S. penicillata* mate and the female flies place a single larva in the opening of the snail shell. With the naked eye the flies are very difficult to distinguish from bush flies.

The larva feeds on the flesh of the resting snail, killing it.
It pupates and after about 18 days emerges as an adult fly.

The emerged adult flies mate and the reproductive cycle starts again. Several generations are possible over the summer.

During the winter the pupal stage remains within the snail shell for up to six months, emerging as an adult fly at the start of summer.

Fly release

Fly releases occur in spring, summer and autumn at field sites with a high number of adult conical snails and a total snail population of over 200 snails/m^2.

Ideal release sites are undisturbed revegetation areas near a crop.

Flying high for snails

As a trained entomologist specialising in biocontrol, Megan Leyson B.Sc (Hons), SARDI, was delighted to return to the labs. and paddocks, following a period working in research administration and politics.

This combination of skills has enabled Megan not only to expand the work on the fly *S. penicillata* which parasitises the conical snail *C. acuta* but also to keep grain growers up to date with the latest results and control options from the SARDI snails research work.

Managing the fly breeding program and 20 release sites is a demanding task. Duties are shared between Megan and her technical team of Nathan Luke and Kerrin Bell.

In a year the team make weekly trips to the Yorke Peninsula - for the fly release program in the summer and for snail baiting trials during the cooler months.

"Current funding extends the fly program through to 2005. We aim to develop more nursery sites during summer 2003/04 with the longer term aim of establishing fly populations across all areas of the State which contain dense populations of conical snails."

At each site over 200 flies are released inside a 1.5m by 1.5m mesh tent. To help ensure maximum survival the flies are given food and water. The tent remains at the site for several weeks before being removed and the flies are released into the area. Following release, a sample of snails is taken from the site and levels of fly parasitism and establishment are checked over the longer term.

Researcher Megan Leyson, SARDI, with the parasitic fly rearing operation. Since autumn 2000 over 6000 S. penicillata have been bred and released at 20 sites on the Yorke Peninsula, SA.

Figure 6: Release sites on the Yorke Peninsula

Parasitic flies have been recovered from five of the six 2000-01 release sites and also from ten of the twelve 2002 release sites. At the time of publication, parasites had dispersed up to 1km from some of the original release sites. Monitoring of fly dispersal and establishment will continue during the 2003-04 summer and beyond.

Other control options tested

Tillage and snails

Farmers have expressed concern that adopting no-till farming results in an increase in snail numbers. These concerns are justified.

Research has found that burying snails especially during mating appears to be effective at reducing snail populations.

Multiple passes with narrow points can provide some burial, but these are not as effective as shears or full-cut discs used at the first working in a conventional tillage system.

A single sowing pass with narrow points does not reduce snail numbers at the surface.

In light calcareous soils aggressive tillage with a 10cm shear reduced conical snail numbers by between 40 and 60% from the initial surface numbers.

Full-cut discing can reduce surface numbers even further.

Multiple tillage passes were found to bury the majority of snails but some were brought back to the surface with each subsequent pass.

Just because a snail was buried did not mean that it was dead, but how long a snail can remain buried and alive has not yet been established.

Timing of tillage is also important. Tillage which causes snail burial before or during mating physically separates mating snails disrupting egg laying and results in less juveniles in the population. **Less juvenile snails can result in less crop damage at emergence and contamination at harvest.**

A late tillage with narrow points after egg laying has occurred will not be effective at reducing snail numbers. This is precisely the sowing system adopted by no-till operations.

Farmers using no-till farming systems need to make use of all other tools available to keep snail numbers to a minimum. Stubble management and early baiting provide a possible alternative to control by tillage.

Parasitic nematodes and fungi

Some naturally occurring nematodes are parasitic on snails. Surveys and field and laboratory studies in SA and overseas have not uncovered any promising candidate nematodes for snail control in southern Australia.

Other research has focussed on the impact of a strain of the fungus *Trichoderma harzianum* on snail egg mortality. Although it was isolated from snail eggs this strain of fungus has been found to be ineffective against snail eggs. Researchers are investigating other fungi which may infect snail eggs.

Pesticide sprays

Researchers tested five commonly used pesticides which growers had reported killed or repelled snails. Treatments were Diquat® (Reglone 200g/L) at 625ml/ha, Copper oxychloride at 4.9kg/ha, Copper sulphate at 10kg/ha, LeMat® at 375ml/ha, Gramoxone, 250g/L at 1L/ha. The control treatment was water.

None of the treatments had any significant effect on snail numbers or demonstrated any repellent effects.

There is no evidence to support the use of any of these products for broadacre snail control.

Fenceline weed control

Snails do not breed on open ground. Maintaining a weed free zone approximately two metres each side of a fence line helps remove a potential breeding ground.

Answers to practical questions

It is surprising that Yorke Peninsula agronomist Bill Long ever has time to sleep.

In addition to running a thriving consulting and research business he is also involved with the family farm, recent State Chairman of TOPCROP and currently chairs the Snail Management Advisory Group which brings together all parties involved with snail issues.

Bill and his team have been instrumental in providing scientific answers to questions about snail control raised by farmers. This work includes the research on the impact of tillage, summer weed control and stubble burning.

With his passion for TOPCROP, Bill was part of the team that developed the TopActive Snail Management packages which have helped growers across the southern region access the latest information on snail control.

Preventing grain contamination by snails

Preventing grain contamination by snails

Effective use of the **'Bash 'Em', 'Burn 'Em', 'Bait 'Em'** strategy in the autumn, winter and spring will have minimised but may not have eliminated snails at crop maturity.

Where snail numbers in autumn remain above the control threshold of $20/m^2$ in cereals or $5/m^2$ in pulses and canola there is a strong possibility of snails being present at harvest.

Thresholds for snail management at harvest are hard to prescribe. This is because it is the relationship between size and shape of snails and grain, the type and number of snails in this size bracket and the location within the crop canopy, which determines the need for header modifications.

Seasonal conditions influence the rate of growth and definitely influence the onset of aestivation, ie the movement of snails up the crop. To assess the potential need for harvester modifications snail numbers and sizes should be monitored three to four weeks before harvest. Snail sizes can increase between monitoring and harvest.

At harvest it is the snail infestation in the upper canopy, above the targeted crop cutting height that causes contamination of grain.

By harvest the opportunities to minimise grain contamination by snails are limited to:

- minimising the intake of snails into the harvester
- maximising snail and grain separation within the harvester
- post-harvest grain cleaning.

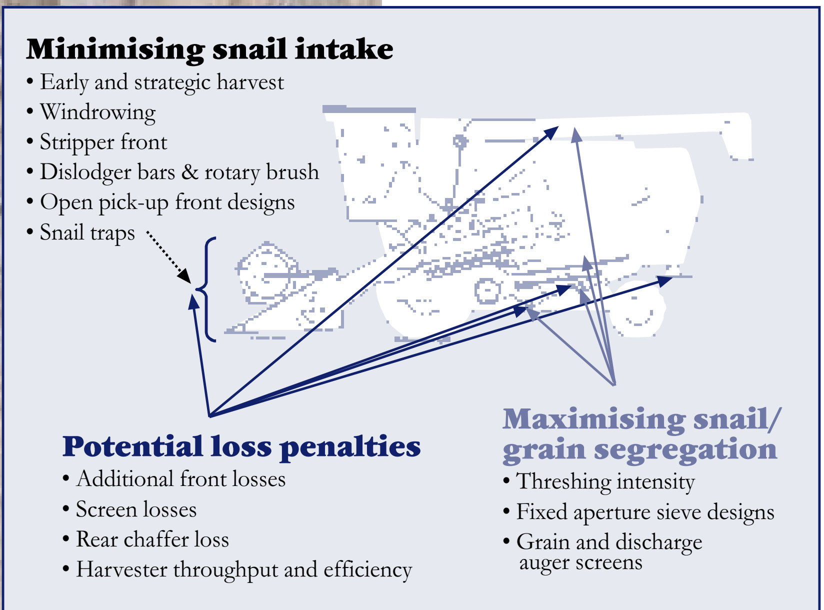


Figure 7: Harvester modification options to minimise grain contamination by snails and associated loss penalties

Research found that a combination of header modifications can drastically reduce the number of snails entering the grain sample (see Figure 7). To achieve this reduction there is a general trade-off between reduced harvester throughput and/or increased grain loss.

Grain quality receival standards detail the maximum allowable number of whole snails in 0.5 litre or 200g. These are published annually by grain storage and marketing organisations.

Snails and ripe crops

- **The problem of same size snails and grain is the main challenge for separation at harvest**
- More snails are found in the upper canopy as the harvest season progresses. Round and conical snails both migrate up the plant in response to hot and dry weather
- Smaller snails tend to remain on the ground in greater numbers and later into harvest compared to larger snails
- Early in the harvest season, snails are more likely to respond to a light rain shower and descend to the ground for a short period of time. Snail movement response to rainfall reduces later in the harvest season
- Conical snails are often found in sheltered locations, eg between leaf and stem and are especially hard to dislodge
- Round snails in cereals are more likely to be crushed by harsh threshing settings before reaching the sample. In pulses, a greater proportion may reach the sample intact
- Conical snails are a potential problem with all grain types as they are more likely to reach the sample intact
- Snails become significantly harder to dislodge from the crop canopy as summer progresses.

Minimising snail intake

Windrowing

Windrowing (swathing) cereal crops can reduce the number of round snails eventually entering harvester. An average of 55% and up to 75% of round snails, counted in the crop, were dislodged by windrowing a barley crop. This is in comparison to direct heading at the same height on the same day.

Windrowing cereals earlier and in cool conditions resulted in a lower number of snails in the windrow. This is due to the snails being significantly easier to dislodge earlier in the harvest season. There is evidence that snails leave cereal windrows after a period of time.

In crops which were windrowed green and left to dry, eg canola and pulses, snails were found to move into the windrows. This can result in more snails entering the harvester.

Farmer experience suggests that snails tend to invade windrowed bean crops if windrows are left for any length of time and that moisture events cause snails to move into canola windrows.

Snails can be dislodged from faba bean windrows immediately in front of the harvester by a short length of iron or old flat conveyor belt gently brushing the windrow. This operation is done with a separate vehicle, eg a ute fitted with an extension arm on one side to which the iron or conveyor belt is attached at the correct height above the windrow.

When harvesting windrows using open fronts fitted with crop lifters, PVC pipe covers should be fitted over the cutter bar to mask the unused width of the front. This improves the feeding uniformity of material into the machine and minimises the intake of snails perched on the stubble. Research work has also shown that open raking pick-up designs can significantly reduce snail intake (50% reduction) relative to the conventional belt type windrow pick-ups. This is due to snails being shaken through the open raking pick-up, an action which can be maximised by a slight lead on the pick-up speed.

Harvesting snail infested paddocks after a light shower can help reduce snail intake. A 2.5mm shower early in the harvesting season can be enough to make snails move down the crop but there is minimal moisture absorption by the grain allowing delivery criteria for grain moisture to be achieved.

High cutting height

A rotary stripping front mostly harvests the grain heads.

The stripping front reduced snail numbers reaching the grain sample by 50% relative to standard open fronts in wheat crops.

Further reductions in grain contamination can be achieved when the stripping front is used in combination with a dislodger bar.

Harvesting capacity with the stripper front can increase by 25% or more, compared to an open front in the same conditions.

Rotary stripping fronts are most suitable in thick standing cereal crops of even height, and on even terrain.

A cheaper but less effective alternative is to raise the cutting height with an open front to minimise bulk crop intake. Conversely, in crops heavily contaminated with snails, the intake of more straw may help absorb moisture released from crushed snails and facilitate ejection over the chaffer.

Both systems result in more standing straw, which may cause additional residue handling problems at sowing.

Dislodger bars - key points

- Designed to knock snails from standing crops
- Most suited to large round snails high in the canopy
- Appropriate when harvesting heavily infested crops – may only be required when harvesting paddock perimeter
- More effective and lower losses when used early in the harvest season
- All designs are a compromise between reduction in snail dislodging and grain loss.

Dislodger bars reduce snail intake decreasing the quantity of snails and snail muck that has to be dealt with inside the header.

Snail dislodger bars are attached to the windrower or approximately two metres in front of the cutter bar on the harvester (see photos Page 28). The objective is to flick snails off the crop and onto the ground, whilst minimising crop damage and the chance of snails landing on the cutting platform. **Therefore a design that produces the best balance between snail reduction and grain loss is required.**

The effectiveness of snail dislodger bars is determined by: design and setting, crop conditions, speed of travel, snail type, position and density.

Grain losses increase as snail dislodging performance increases. This means bar design and setting must be optimised for the individual crop and crop condition, if crop losses are to be minimised.

Dislodger bars are most suited to removing large round snails. Results to date confirm dislodger bars are two to six times more effective at removing round snails than conical. This means, the dislodger bar is not a suitable solution for crops infested with conical snails.

Despite significant reductions in snail intake, dislodger bars do not always result in a significant reduction of snails in the grain sample. This is because it is the larger round snails which are primarily dislodged, however these are also the more likely to be crushed in the thresher or scalped by the chaffer. Where small and conical snails are present in the crop these will continue to be found in the sample if a dislodger bar is the only harvester modification applied.

Trials, in cereals, with a single rigid pusher bar set close to cutting height generally gave an acceptable balance between snail dislodging and grain losses.

In delicate crops such as faba beans, dangling chains (450g/m chains at 50mm spacing) caused 85% dislodgement but 7% yield loss, and agricultural V-belts (100mm spacing) caused up to 60% dislodgement at 2 to 3% grain loss, which may be a better compromise.

In preliminary trials a rotary brush, which is able to provide a soft to harsh brushing action, proved to offer a versatile solution and caused lower grain loss.

Engineering solutions for snails

Research engineer Dr Jack Desbiolles, University of South Australia, has specialised in applying engineering solutions to agricultural problems.

With funding from GRDC, Jack and his research team have worked with farmers on Yorke Peninsula to evaluate, modify and develop systems that minimise snails entering the harvester and help separate snails from the harvested grain.

Variability of snail populations across the paddock makes this type of research a real challenge.

"The support, innovation and enthusiasm of local farmers has been an enormous help in generating outcomes from the project.

"We have used a first principle approach to produce management solutions at harvest."

A 'big' thanks must go to all the farmers and businesses which have supported our trials with time and equipment. A special mention must go to SYP Alkaline Soils Group Coordinator and Project Leader Michael Richards and our header driver Roger Stevenson.

Jack's work has run since 2000 and will continue for one more harvest.

Dislodging is most suitable when windrowing crops or for crops which are harvested early. This is because as the harvest season progresses the force required to dislodge snails from crops increases. In a seven week period, a seven to ten fold increase in the dislodging force required to remove snails from a faba bean crop was recorded.

The use of a dislodger bar should be decided by assessing the snail population by number, size and location in the crop, on a paddock by paddock basis. Checks should be made of the paddock margins and interior as margins are often more heavily infested and a bar may only be required for the perimeter rounds.

All dislodger bars were tested on an open front mounted on a 1420 Axial Flow International Harvester purchased for the project.

Choice of dislodger bar is always a compromise between cost, weight, level of snail removal and grain loss.

Rigid dislodger bar design

Ideally, dislodger bars should be height adjustable to cater for different crop conditions. The distance ahead of the cutter bar should be adjustable to prevent snails flicking back into the header and to meet transport restrictions.

Features to consider when designing a snail dislodger bar include:

- minimising weight
- overall rigidity
- versatility across a range of crops
- adjustability - preferably independent of the platform height and whilst in operation.

Yorke Peninsula farmers Jamie Koennecke (L) and Richard Murdoch (R) mounting the arms of their homemade dislodger bar.

Dislodger bar for standing cereals

The pusher bar concept is only appropriate for cereal crops

- Lower edge set 50-75mm above cutting height, but shallower adjustments may be required to minimise losses in mature crops
- Set at approximately 2.0-2.2m ahead of the knife to flick snails to ground
- Up to 80% round snails dislodged from harvest zone in cereals
- 2-3% yield loss, but losses can double when travelling against barley hook
- Rigid steel Duragal Rail profile [120x48x2mm at 4.5kg/m length] or lighter and flexible PVC pipe [125mm diameter] are possible designs.

Dislodger bar for peas and beans

Dangling agricultural V-belts set at 100mm spacing.

- 35-60% round snails dislodged from harvested zone
- 4-5% yield loss
- 100mm spacing more effective than 200mm
- Lighter than chain alternatives
- If accidental intake, low risk of harvester damage.

Double dislodger bars

A double dislodger bar resulted in fewer snails in the sample but extra grain losses can quickly outweigh this benefit. Its use is more suited to tougher cereal crops that are less susceptible to mechanical damage and where snails are found higher up the plants. Accurate set-up, to optimise a 'double knock' effect at a particular harvest speed, is essential. In trials, the second bar was fitted about 50-70cm behind and 10-15cm below the first bar and operated at a forward speed of 5km per hour.

Rotary brush

Early testing of polypropylene brushes showed performance levels close to that of a rigid pusher bar (ie. up to 70% round snail dislodging), but with proportionally lower crop losses.

A rotary brush prototype was developed in response to seeking more versatile dislodger bar designs suitable for use in a wide range of crop conditions, including pulses.

The brush consists of five rows of 500mm long 2.8mm diameter polypropylene bristles, spaced 50mm apart and fitted onto a 150mm diameter tube giving a brush unit with an outside diameter of 1.25m. The 6m wide unit is hydraulically driven using a small independent gear pump and tank kit with a pressure relief valve, which is mechanically powered from the harvester front drive-shaft. The front reel hydraulics are shared to alternatively activate the height setting of the rotary brushes, via a three-way valve.

This rotary unit is fitted to the header front so the edge of the brush is just clear of the normal finger reel and able to rotate in either reverse or forward directions, (see Table 3).

Rotation speeds ranged from 0 to 160rpm and can be adjusted whilst rotating.

During testing the rotary brush showed a high potential for dislodging snails whilst being gentle enough for delicate crops like peas and harsh enough in tougher crops like wheat. This was achieved by changing the penetration depth into the crop, the rotational speed (in relation to forward speed) and direction of rotation.

The rotary brush concept provides a versatile and an adjustable, on-the-go, dislodging action to optimise performance in changing crop and snail conditions.

Table 3: Example of the performance of the rotary brush set over the 27-52rpm range compared to pusher bars operating in tough (resistant to mechanical damage) wheat crops

Rotary brush performance relative to	Snail material reaching the cleaning sieve	Losses relative to double pusher bar
Double pusher bar	25-40% reduction	-
Single pusher bar	45-70% reduction	Similar to slightly higher

With the rotary brush crop loss levels are very dependent on crop and crop maturity. For example in a similar test to that in Table 3, a barley crop showed 5% extra crop loss relative to a standard open front. In peas, a slight tickling action at 73rpm in the standard direction resulted in 40% reduction in whole snail flow rate to the cleaning sieve, at no detectable extra loss.

The rotary brush prototype cost of approximately $8000 this may be reduced by further improvements to the design.

Maximising snail and grain separation

High threshing intensity

Increasing the intensity of threshing is a harvesting technique that can effectively crush snails. Any crushed snails can be removed later with air separation. Combining high intensity threshing with a higher intake of straw will help to minimise recycling with the tailings. This is because the snail meat becomes attached to the straw and is then ejected as rear losses. These techniques are only suitable for larger round snails. They can result in clogging the grain transfer and sieve components and can also physically damage harvested grain.

Yorke Peninsula farmer David Edwards shows Ian McKinnon, Chair of GRDC Southern Panel, the mixture of dust and squashed snails which built-up on the augers and sieves whilst harvesting. The use of a dislodger bar and high bulk intake can help reduce caking inside the harvester.

Fixed aperture sieves

- Where there is a significant difference in the size of snail and grain, sieve design can effectively reduce the number of snails entering the grain box
- The removal of snails larger than the grain is termed scalping, where they are smaller this form of separation is termed sieving or screening
- Where snails and grain are of a similar size, a screening or scalping approach produces unacceptably high grain losses or inadequate snail removal
- Adjustable louvre sieves are suitable for large grains such as faba beans
- Fixed aperture sieves rely more on physical screening and less on air separation.

In Australia, harvesters are generally fitted with adjustable louvre sieves in both the chaffer (upper sieve) and shoe (lower cleaning sieve). With these sieves snail and grain separation within the harvester is primarily reliant on air separation, and to a lesser extent on physical screening. Separation is promoted by the action of air over the whole surface of either standard or air-foil louvre designs. Indications at this stage are that the air-foil louvre design is better able to separate conical snails than standard louvre designs.

To improve separation of snails from small to medium size grain, the chaffer and shoe can be replaced with fixed aperture sieves, with appropriate specifications for both the grain being harvested and the snail contaminants, (see Table 4). Louvre sieves are successfully used with bigger size grains (beans).

For typical harvest applications, fixed aperture sieves have a similar or greater open area than louvre sieves. The change to fixed aperture sieves increases the reliance on physical screening and lowers the reliance on air separation.

Fixed aperture sieves result in a reduction in harvester capacity due to more material being recycled via the repeats. Fan speed should be reduced to minimise repeat recycling and control chaffer losses. Careful selection of aperture size and of open area-ratio selection is therefore critical for optimising the harvester efficiency and maximising snail/grain separation (see Table 5).

Three types of fixed aperture sieve design have been tested.

- Punched hole screens (PHS) – commonly circular, hexagonal and oblong hole shapes
- Expanded metal mesh (EMM) – diamond-like opening shape
- Woven or welded wire meshes (WWM) – square or rectangular aperture shapes.

Pursuing the pest

It could be argued that snails caused Michael Richards to stop farming. Not because they became too great a problem but because he saw the need for more research and extension on these pests.

In 1999 Michael and a group of Southern Yorke Peninsula farmers organised the Stalking Snails Day on his farm at Minlaton. With over 500 in attendance the Day highlighted the grower demand for information on snail management and the innovations growers had developed to try and combat this pest.

Since then Michael has dedicated much of his time to securing research investment into the snail problem and sharing his knowledge on snail management with farmers across South Australia and Victoria.

Much of the snail research in South Australia is carried out at the SYP Alkaline Soils Group trial site, based on part of Michael's farm.

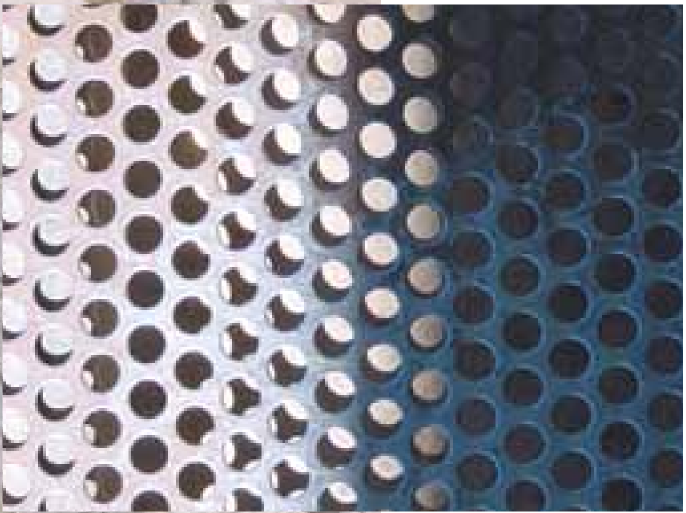
"Whether we like it or not snail control has now become a vital part of our daily farming operation, just like weed and disease control.

"Using an integrated management program is essential to achieve cost effective snail control. For growers on SYP this means everything from stubble management to enterprise selection, harvest practices and grain cleaning.

"Growers in other areas may not have the conditions to aid in the build up of large snail populations but they must learn from our experience, and take actions to prevent snails from becoming such a problem.

"Growers now have clearer information to assist them in developing an effective snail management strategy."

In addition to being Group Coordinator for the SYP Alkaline Soils Group he is Project Leader for the Harvest Technology for Quality Grains Project. Michael has also been part of a team of farmers and engineers who have developed an inclined belt specifically to remove conical snails from canola.



Punch hole screen (PHS)

The hole size and shape are chosen to suit crop type and seed size. The higher the open area rating of the screen (ie the greater the proportion of screen that is occupied by holes) the higher the sieve capacity Sieves with a high open area rating must be sufficiently thick to provide enough screen rigidity (eg 1.6mm minimum thickness is recommended for open areas > 40%). However, screen cost is also proportional to both thickness and open area rating.

The smooth part of the screen should be mounted face up in the harvester.

Expanded metal mesh (EMM)

The diamond like openings are characterised by long and short 'way lengths', which determine a range of opening shapes and sizes. These openings can be orientated either crosswise or lengthwise on the sieve.

Results to date suggest lengthwise direction (parallel to travel) is less effective at separating conical snails and increases repeat ratios. Therefore a crosswise orientation is recommended. Because of the design characteristics of EMM screens, there are two possible screen orientations, under the crosswise setting, which can also affect performance.

Knuckle joints

When orientated to expose a lower effective open area to the wind (ie the knuckle joints of the openings facing to the rear of the header), the sieve was found more effective at diverting snails to the repeats, but this also resulted in lower harvester throughput and higher recycling ratio.

EMM screen directions are mostly used with the knuckle joints facing to the **front** of the harvester. Generally, EMM screens tend to be more sensitive to clogging but may provide significant improvements with conical snail separation.

Woven and welded wire mesh (WWM)

This sieve material is characterised by wire diameter and size of the square aperture. Woven mesh can show large variation in actual aperture size relative to the nominal values. To maximise screen capacity, the wire diameter should be the minimum required for adequate rigidity and the hole size must both suit seed size and maximise the open area rating. These meshes need to be secured at the edges after cutting to size, to ensure the mesh does not fray. The welded rather than woven material is less likely to trap residue and promote clogging.

Chaffer only or chaffer and shoe set-ups

To date, results show that changing the chaffer sieve to a fixed aperture screen, and removing or fully opening the shoe louvre sieve results in limited capacity due to high potential rear losses. With only a fixed aperture chaffer sieve, threshing needs to be more thorough as unthreshed heads/pods typically end up as rear losses. This option offers the practical benefits of avoiding the removal of the shoe which can be complicated in some harvesters.

Currently, the recommended option is the upgrade of both chaffer and shoe set-ups, which allows a more effective two stage separation process. That is, the choice of screens of one or both sieves can be optimised to minimise rear losses and maximise throughput independently of one another.

In situations where repeat ratios are low in grain and high in snails, and where harvester clogging risks are high, an option is to waste the repeats onto the ground by opening the repeat doors.

Table 4: Examples of sieve performance in barley crops

Screen type and size: Chaffer / Shoe	Shoe sieve performance (%R - round, %C - conical snails intercepted)	Ranking of chaffer losses (% yield)	Harvester performance (% recycling ratio and throughput)	Comments
Adjustable louvre 5-6/16”/4/16”	R: 15-40% C: 10-40%	lowest (<0.5%)	Reference throughput and lower recycling ratios (5-40%)	Control
Circular punched Hole combo 1 7.9mm/6.3mm	R: 70-75% C: 60%	highest (>5%)	Highest recycling ratio (>100%) and reduced harvester throughput (-25 to -50%)	Best sample obtained with up to 55% reduction in snail contaminants
Hexagonal/circular punched hole combo 2 9.5mm/7.9mm	R: 20-55% C: 20-50%	1-1.5%	Intermediate recycling ratios (20-40%), similar harvester throughput	Can result in lower snail count in sample (up to 35-40% measured reduction)
Woven wire mesh 8mm/6.3mm	R: 30-40% C: 15-20%	1-1.5%		
Expanded metal mesh (standard direction) 28x9mm/19x7mm	R: 50-75% C: 30-40%	2-4%	Higher recycling ratio (40-100%), similar harvester throughput	Can result in lower snail count in sample (up to 50% measured reduction)

Example sieve combinations

The optimal chaffer/shoe set-up varies with each crop situation eg variety, season, weeds, snails etc. Table 5 contains the details of the sieve set-ups which performed well over a range of conditions. Where required, use of intermediate screen sizes can improve snail removal but this increases the risk of significantly reducing harvester efficiency.

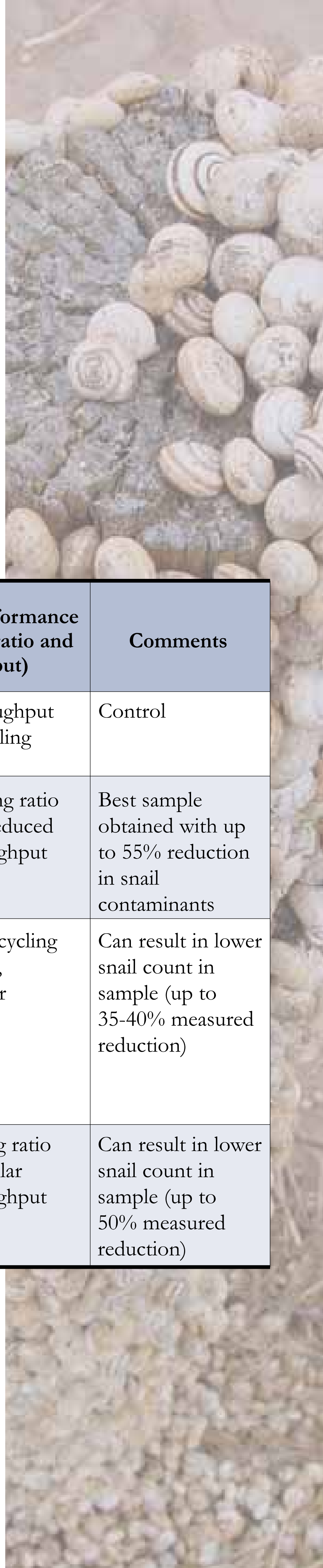


Table 5: Chaffer and shoe screen types and sizes which performed well in the specified crop over a range of conditions

Crop	Chaffer screen			Cleaning screen (shoe)		
	PHS	**EMM**	**WWM**	**PHS**	**EMM**	**WWM**
Canola	4.76mm round 3.97mm round	7x19mm 6x16mm 5.5x10mm	3.25mm	3.25mm round 2.41mm round*	3.5x6mm	--
Peas	11.0mm round	--	10mm	9.53mm hex 9.53mm round 8.5mm round*	--	8mm
Barley	9.5mm hex	9x28mm	8mm	7.94mm round	7x19mm	6.3mm
Wheat	9.5mm hex	9x28mm	8mm	6.3mm round or square	6x16mm	6.3mm

**higher risk of clogging depending on seed size.*

Sizes are the hole size (PHS), nominal mesh size (EMM) and nominal aperture size (WWM).

Chaffer and shoe screen size should be selected based on a screen's ability to allow harvested grain to easily pass through the screen.

Cleaning contaminated grain

New research has identified differences in the physical properties of grain and snails that can be used to help improve the performance of cleaning snails from grain.

Using the differences in some of the physical properties of grain and snails ie weight, shape, size and strength, is the key to successful separation of both round and conical snails from grains.

A combination of cleaning systems is generally required to clean grain to receival standards without excessive grain losses.

Machines that roll or crush the grain provide a good on farm cleaning option in terms of throughput, losses, snail removal and cost.

The results presented here will help growers select the most appropriate cleaning system and its set-up for the removal of snails from different grains. Cleaning is the last tool in the integrated snail management package, which includes stubble management, baiting and harvester modifications.

Physical Differences

Gravity separation – Snail separation using gravity or density is possible. This is because a significant difference exists between the bulk density of both round (3-12mm diameter) and conical (2-8mm length) snails and four tested grains: canola, barley, peas and lentils. As snails dry they become lighter and the difference between their bulk density and that of grain increases. Therefore gravity or density separation for snail removal should be carried out after at least a few days of grain storage.

Air separation – With the exception of peas, trials showed that air separation results in heavy grain losses as barley, canola and lentils all have a similar terminal velocity to round and conical snails. This also explains the limited effectiveness of the traditional louvre sieves on harvesters relative to the potential of fixed aperture sieves. Terminal velocity is the minimum air velocity required to keep a single grain/snail suspended in an upward stream of air. Air separation is useful for pre-cleaning dust and light material out of a dirty sample and for removing dried snail meat and shell fragments after grain has been rolled. The air velocity and flow rate required depend on the design features of a cleaning system.

Screening/scalping – Screening in the harvester or through a cleaner can reduce the number of snails but separation to meet receival standards will, in most cases, result in unacceptably high grain losses. To achieve good results a significant difference in grain and snail size is required. In contaminated cereal samples, 10 to 50% snail removal was achieved with screening whilst grain loss was only about five percent, (see Table 6). As grain loss increased, snail removal generally improved except in lentils where 50% snail removal was the maximum achieved.

Table 6: Typical results from screen test performed for snail separation in harvested grain

Grain type	Screen	Grain loss	Snail removal
Barley , wheat	25mm by 2.6mm slot	5%	50%
Peas	5.15mm diameter round	2%	10%
Lentils	25mm by 2.65mm slot	6%	48%
Canola	2.2mm diameter round	5%	12%

Rolling/crushing – Rolling and crushing snails is feasible for all hard grains, ie not canola, and can be achieved without high grain losses. This is because the mechanical strength of cereal and pulse grains is quite high in comparison to that of snails. The mechanical strength of grains and snails is highly influenced by their moisture content. To minimise grain damage and losses, rolling should be carried out at the optimum grain moisture content of 13 to 16% (see Table 7).

Cleaning machinery

Snail crushing rollers

The efficiency of removing snails by crushing was tested using a Shmik™ roller. This consists of two parallel rollers of about 250mm diameter, each coated in food grade polyurethane of suitable hardness. The rollers rotate in the opposite direction and are set at a narrow clearance, approximately 1mm, to crush the snails with minimal grain damage as the mixture passes between the rollers.

The Shmik™ roller has a capacity of between 15-25 tonnes per hour. In the trials where the grain was pre-scalped and re-cleaned following rolling, an average snail removal of 81% was achieved with a grain loss of between 4-6% for the whole process. The on-farm use of the roller-crusher drastically improves the performance of common grain re-cleaning equipment, which allows farmers to meet grain quality receival standards.

Table 7 shows the set-up and grain moisture levels required to achieve the most efficient cleaning, established by the trials. Accurate settings should result in about 2% grain loss with maximum snail crushing. This can be measured by weighing 5kg of contaminated grain and passing it through the rollers. The processed grain should be collected on an appropriate size screen (see Table 6) with the kibble falling through the sieve and collected in a bucket. If the kibble weighs less than 100g the set-up is good.

Overall performance of the roller depends on clearance between the two rollers, grain moisture, roller hardness, speed of rotation and feed rate of grain into the rollers.
The roller provides an economic, high capacity, versatile and effective on-farm cleaning option for snails but alone may not achieve a sample that meets receival standards. Pre-scalping and post screening using a traditional grain cleaner, either side of the rolling operation, are generally required for receival standards to be achieved.

In addition to the snail roller, a field bin and auger are required. If cereals and pulses are to be cleaned, two sets of rollers of different hardness are recommended.

Table 7: Snail crushing roller set-up for different grain types

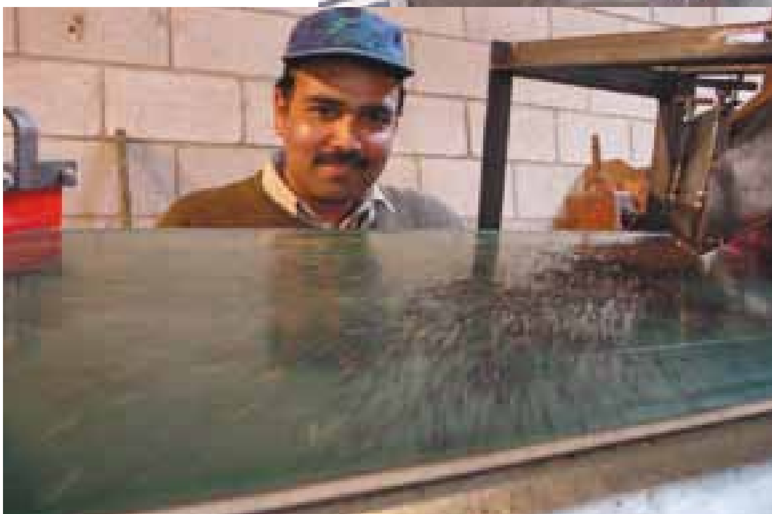
Grain type	Grain moisture content	Roller clearance	Roller rating
Cereals	12-14% or less	Less than 1mm	Hard roller
Peas	14-15%	1-2.5mm	Soft roller
Lentils	12-14%	1mm	Soft roller
Faba Beans	14-15%	Less than half the width of the seed	Soft roller
Canola	Unsuitable with current rollers		

Other cleaners

The trial also looked at three other cleaning machines, the results of which are summarised with those of the Shmik™ roller in Table 8.

The **Camas™** machine is a density separator combining air-separation with vibrating fluidised bed segregation. This gave the best results and is suitable for all grain types, has a high throughput but is expensive and not currently suitable for on-farm use.

The **Nufab rotary screen** can achieve cleaning to meet delivery standards but the results for snail removal were variable and grain losses can be high. For snail removal this machine is most suited as a pre-cleaning treatment or as a polishing machine for a final clean after grain has been rolled.



Researcher Salil Sharma (pictured right), formerly of the University of SA, assessed the performance of the farmer designed inclined belt separator. This separator concept requires suitable pre-scalping of the sample to remove bigger foreign particles, and provides the only practical solution to the removal of small conical snails from canola. The capacity is low but a new design with a higher capacity is currently being developed. This is a static machine but a transportable model could be developed.

Table 8: Comparison of grain cleaning technologies evaluated for post-harvest snail removal

Technology	Application	Energy required KWh/ tonne	Capacity t/h	Grain loss %wt	Snail removal %	Pre/post cleaning require-ments	Approx. cost $
Inclined belt separator	Canola	2.4	1	4%	82-96%	Pre-screening	20,000 to 30,000 relative to capacity
Camas ™ machine	All grains	1.6-3	13-25	3%	93-100%	Pre-screening (optional)	80,000-100,000
Shmik™ rollers	Cereals, and lentils	0.6-1	15-25	4-6%	81%	Pre-scalping and post screening	12,000-15,000
Nufab rotary screens	All grains except canola	2.5	30	4-9%	73-100%	It is a pre-cleaner	65,000-75,000

Farmer experience

Counting down to zero

Yorke Peninsula farmers Andrew and David Hastings have seen a significant reduction in the number of snails on their farm since adopting a range of snail control techniques.

Andrew counted an average of 50 round and conical snails per square metre along the fencelines when he starting monitoring snail numbers three years ago. In 2002 this number fell to between zero and 20 snails per square metre along the fence and between 10 and zero further into the paddock.

The Hastings maintain a simple rotation of durum wheat, barley and medic pasture on their 800 hectare property. Pastures and stubbles are grazed by 200 ewes.

"Snail numbers appear to change with the season and the crops grown. In medic pastures we see a large increase in snail numbers," said Andrew.

"If 2003 is a more normal rainfall year we may see numbers increase. Now that we are using integrated snail control I would be disappointed to see snail numbers exceeding $50/m^2$."

"Conical snails have only really been a problem since we started growing durum wheat in 1995, I guess this is because the delivery standards are much tougher."

To help ensure their cereals meet the ever tightening delivery standards the Hastings start their snail management after harvest by rubber tyre rolling their stubbles.

"We have tried 'cabling' using a 100m chain on the pastures but felt the chain was too aggressive on stubble."

"We like rolling as it not only knocks the snails around but also helps with stubble breakdown."

Following the opening rains some paddocks are fire harrowed to kill germinating weeds. Although this only gives a partial burn the Hastings find that fire harrowing in combination with stubble rolling has helped reduce snail numbers.

In the past Andrew has carried out broadacre baiting at 10kg/ha but this year only plans to bait the fencelines. Snail numbers will be monitored and multiple bait applications may be used if snail numbers persist.

"If I could cut bait out of my control program I would be delighted, it is expensive and yet another chemical that we are adding to the soil."

"Where we do bait we tend to use the higher rate of 10kg/ha as we find this gives more effective control irrespective of snail numbers."

The Hastings have used a ridged pusher bar on their harvester but find the rotary action of their harvester and good adjustment on the concaves is sufficient to squash any large snails before they reach the grain tank.

Smaller round and conical snails that reach the grain sample are removed using a Hannaford screen (2.2mm slotted screen) enabling all grain to meet delivery standards.

Winning the war on snails

How would you react to a snail count of up to 6000 round and conical snails per square metre in a pasture paddock? Warooka farmer Graham Hayes took this pest explosion in his stride as he now has the tools to control such snail densities.

Farming 1000 hectares with his son Chris and wife Raelene, Graham has become accustomed to dealing with snails. In 1984 the Hayes' changed from a crop, volunteer pasture, crop rotation to continuous cropping including sown, grass free pasture. The whole farm which is mainly a grey calcareous sandy loam is direct drilled using knife points and press wheels.

"Snails have been a recorded crop pest in the Warooka district since the 1900's but it was not until 1988 that our farming system became crippled by snails when our malting barley was downgraded to feed because of snails," said Graham.

"Up until 1999 we controlled snail numbers with bait and had not burnt stubbles for eight years. However, the good, early break to the season in 1999 saw a massive increase in snail numbers on our farm and the majority of crops were down graded or rejected."

Since then Graham has been a key player in snail research and development both as a member of the Snail Management Advisory Group (SMAG) and as group leader for the SYP Alkaline Soils Snails Committee. He has also been successfully using an arsenal of control methods against snails.

Summer weeds are the first line of attack and are controlled by desiccating pea and lentil crops or using herbicide in stubbles and pastures. After harvest grazing, cabling and burning heavily infested stubbles are all control methods used.

Early baiting before egg laying is the next control method and one which Graham believes is vital. At seeding all pea, canola, lentil and malting barley crops are again treated with at least 5kg/ha of bait depending on snail numbers.

Monitoring is a key part of Graham's control program not only inside the paddock but also around the perimeter.

"Scrub and weeds are a great haven for snails. Reinvasion from these areas is an on-going battle and to try and prevent this we vigilantly bait the fencelines throughout the season."

At harvest Graham reaps snail infested crops first and uses a dislodger bar, changeable sieves, a pea plucker and a Shmik snail roller to remove snails from the sample. A grain cleaner is used to screen small snails and residues.

"The snail roller has revolutionised harvest for us, allowing all grain to be delivered and usually at the highest quality standards."

As for the pasture paddock with up to 6000 snails per square metre, Graham sowed this to peas after three passes with a cable and early baiting.

"We were successful in removing most of the snails before egg laying and by using a pea plucker and screening the grain, a snail free sample was harvested.

"I feel we have our snail numbers under control. Providing we remain conscientious with our control methods, we can continue to no-till farm and retain most of our stubbles."

Snail control in stubble minimises the need for baiting

Geoff and Elizabeth Nicholls have taken a team approach to snail management. Elizabeth has been counting snails as part of the on-farm monitoring study while Geoff has adopted management practices to control round snails.

Their mixed farming enterprise at Jabuk, SA grows wheat, barley, triticale and canola as well a runs prime beef on medic pasture and crop stubbles. Soils range from light sands to Bay of Biscay clay.

"In the paddocks we have plenty of round snails but conicals seem to only be around the house," said Geoff.

"It may be fiction but I follow the local rule of avoiding canola in the paddocks adjoining the garden as local farmers are sure canola creates a bridge for conical snails to move into the paddocks."

Geoff's aim is to control snails with stubble management and only resorts to baiting, which he considers to be too expensive, when numbers remain above 100/m^2 at seeding.

Cabling the stubble is at the heart of the Nicholls stubble management program. A single pass with a 300m cable strung between two 120 horse power tractors travelling at about 18-20km/hr resulted in a good reduction in round snails in stubble.

"We started in January with 256 snails/m^2 and seven days after cabling the numbers had fallen to 92/m^2.

"Cabling is so quick, cheap and does not damage the feed that we can easily repeat the operation if numbers are still high."

In canola and barley stubble Geoff finds one pass is sufficient but in wheat and triticale two passes in alternate directions are most effective.

Geoff Nicholls knows the key to a successful kill is to cable on as hot a day as possible.

"Gas up the air conditioner, seal up all the gaps into the tractor cab, as we find we raise lots of small biting insects, and go cabling on 35°C plus days."

Geoff reminds growers that cabling can spark a fire, especially in paddocks with iron stone or when passing 'stobie' poles.

"Although cabling dropped the numbers to 92/m^2 by May numbers had climbed to 138 snails/m^2 and perhaps we should have used some early bait as well.

Before Geoff adopted cabling he modified a lucerne seed sieve to remove snails in the harvesting process.

"The sieve replaces the standard louvre chaffer sieve and consists of rubber balls loosely sandwiched between two punch hole screens. The vibrations of the harvester keeps the balls moving and this action cleans the sieve minimising the chance of blockages.

Geoff Nicholls is always looking for new ways to tackle snails and is interested to learn more about American research which found that instant coffee kills snails. He hopes the Australian researchers are looking into this as well.