Use of the Impact Roller to Reduce Agricultural Water Loss

D L Avalle
MSc(Eng), BSc(Eng), GDE, PGCE, MIEAust, CPEng
Technical Manager, Broons Hire (SA) Pty Ltd, Australia

Summary: The impact roller has been used to improve ground characteristics for many decades now. Of more recent interest to the agricultural industry has been the facility offered by the impact roller to densify the ground, reduce soil permeability and hence have a significant effect in reducing irrigation water losses. Other potential benefits that arise from the use of the impact roller on the floors of water storage reservoirs, growth paddocks and channel banks include reducing the adverse effects on groundwater table fluctuations and soil salinity. Cost benefits also result from the more prudent use of the water resource. The impact roller is shown to contribute to the sustainability of high water use agricultural applications through beneficial effects on soil permeability, and further research is warranted.

INTRODUCTION

Agriculture accounts for approximately 70% of Australia's net water usage (www.abs.gov.au/Ausstats). The rice and cotton industries attract criticism from the urban community and the environmental lobby due to the perceived unsustainability of the high water use. However, rice and cotton production have proven to be economically viable industries and their relative use of water is lower than for comparative crops grown in Australia and similar crops grown elsewhere in the world (www.rga.org.au/enviro/index.asp, www.cottonaustralia.com.au).

The groundwater table in the rice irrigation areas of southern New South Wales (NSW) has risen from around 20m in the pre-irrigation era more than 40 years ago to just 2m or less in most irrigated areas by the early 1990s (Humphreys, et al, 1995). Percolation or leakage from water storages or channels charges the shallow water table and results in a secondary salinity problem, with farmers under increasing pressure to reduce both this leakage and the gross water usage (Caldwell, 2001). Channel losses in the Macquarie Valley have been reported as 20-25%, increasing to 50% in years of low allocation (Giddings, 1998). Recent surveys indicate that around 4% of the total water supplied for rural use is lost to channel seepage (ANCID, 2003).

Impact rollers have been used in Australia for about 20 years and in the agricultural sector for more than 10 years. Operating on the principle of a non-circular drum rotating about a corner and falling to impact the ground, these rollers travel at a relatively high speed. The bases of water storage reservoirs and channels, and their banks, can be treated to reduce infiltration and minimise the adverse environmental effects. The significant depth of influence of the impact roller facilitates its use for the in situ improvement of density in channel banks, frequently without the need to remove soil and rebuild the bank.

The large amount of water used in growing rice and cotton, and in the agricultural sector overall, provides an opportunity for the geotechnical fraternity to contribute to the environmental sustainability of Australian industry. Improving the water retention characteristics by densifying the soil and reducing its permeability using the impact roller has been found to be effective in delivering a more efficient use of our limited water resources.

IMPACT ROLLING IN AUSTRALIA

South Africa pioneered the early development of impact rolling as it is applied today. Its further development and wide range of applications are described briefly in the following paragraphs.

Brief History

Some of the earliest uses of impact to densify the ground include ramming foundations in Roman times to achieve a settlement target and a Chinese swinging weight dating from the Middle Ages or earlier (Clifford, 1978b). The mid-20th Century saw the development of dynamic compaction by French engineers, employing a free-falling mass, a system that was used on a construction site in South Africa in 1955.

The advantages of deep compaction of in situ materials with a mobile dynamic compactor has been recognised at least since the 1930s. A Swedish designer patented a towed impact roller of hexagonal cross-section in 1935, and his patent covered any form of non-circular towable mass. The description of the system in the patent still applies to all impact rollers today (Clifford, 1978b).

About 20 years after the earlier work in Sweden, the South Africans took up the concept. The approach to the treatment of collapsing sands by direct, controllable impact led to the manufacture of the first full-size impact roller, a 7t concrete cube towed by a bulldozer, which caused serious difficulties for the towing unit and the driver. This was followed by a 5-sided towed unit, with springs that absorbed some of the horizontal component of force (Clegg and Berrangé, 1971), as well as other different shapes and masses.

Further development continued through the 1960s and into the 1970s, and in the mid-1970s a 4-sided impact roller was patented, with a torsion bar springing system that evolved into the 4-sided towed impact roller employed today (Clifford, 1976 and 1978a). Broons Hire (SA) Pty Ltd introduced this unit into Australia in 1984, and since then it has been manufactured in Australia and progressively improved by Broons.

During the development period of the 4-sided impact roller, other designs were proposed. Some, such as variable geometry models, were never brought into practical production (Clifford, 1978b). However, 3-sided and 5-sided impact rollers with a pair of impact modules drawn on a central T-bar, now in use, also derive from the early development work in South Africa. Landpac Technologies Pty Ltd imported these units into Australia in 1995.

Figures 1a and 1b illustrate the shape, configuration and masses of the impact roller modules currently available in Australia.

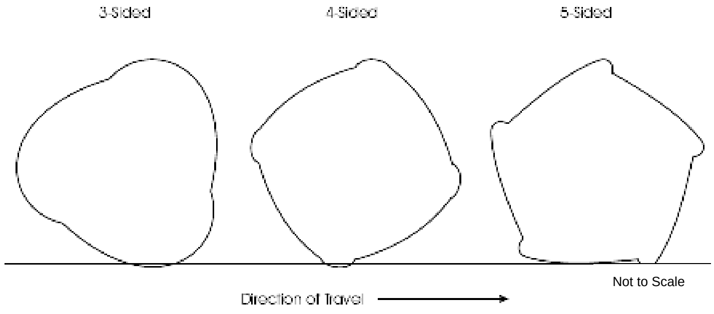

Figure 1a. Cross-sectional shapes of impact roller modules.

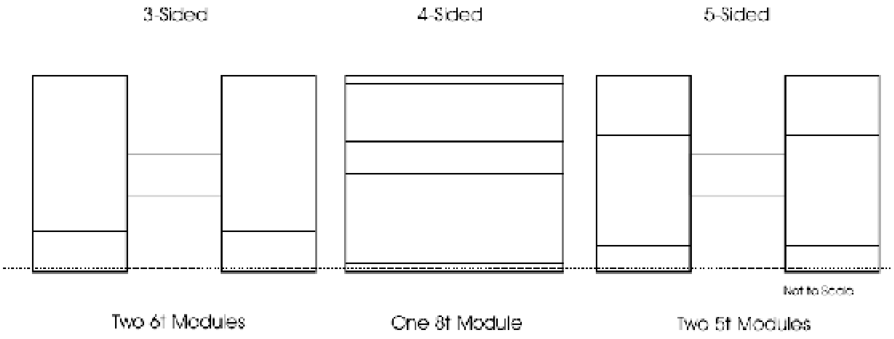

Figure 1b. End view and masses of impact roller modules.

Some Technological Aspects

From its earliest conception, the civil engineering potential of the impact roller was never questioned (Clifford, 2001), and the South African trials demonstrated that impact rolling could have an effect to 1m or more, far deeper than any conventional static or vibratory roller (Clegg and Berrangé, 1971 and Clifford, 1976 and 1978b). Impact rolling was found to be suitable for a wide variety of materials and was far less dependent on the material's moisture content to achieve the desired improvement. The impact roller's ability to equalise the density gradient across a site, developing a more uniform soil "raft", lends itself to a multitude of different applications.

One point of contention is the numerical energy rating attributed to the various impact roller models, which depends on the method of computation and the assumptions made. It is not always clear how the energy is calculated, and both potential and kinetic energy have been utilised in the past.

In computing the potential energy, which equates to a free-falling mass, the factors that need to be rationalised are the effects of indentation at the leading corner (which effectively reduces the drop height), whether the separate modules of the 3- and 5-sided rollers can be considered as a single mass compared with the single 4-sided module, and the possible losses due to horizontal resistance or restraint from the tractor. The full potential energy can only be achieved when the surface is hard enough to permit full lift height to be developed and the impact blow to be delivered over the minimum impact face.

Alternatively, kinetic energy recognises the rotational velocity of the roller mass, but the shape of the modules, the effects of the spring system in the 4-sided module and damping or other potential losses compound the calculations. The 4-sided impact roller has a double-linkage control system that slows the roller mass during the lifting phase as the spring system compresses, causing a slight lag and generating a “dwell time” under load. This indicates that the kinetic energy is fully transferred to the ground, as the motion of the drum ceases. The system then discharges the spring energy, accelerating the module into the downward phase (Clifford and Bowes, 1995).

Stated energy ratings for the various machines should therefore be viewed from the basis on which they were computed, and should be considered, in any event, as theoretical maximum values not necessarily replicable in practice. In fact, the potential energy may rarely, if ever, be fully realised, while the kinetic energy may be a far more repeatable measure.

Range of Applications

Many and varied applications have been undertaken over the years, in addition to the early work on collapsing sands and coal stockpiles. Impact rollers are used for the in situ densification of existing fill, such as on former industrial land or brownfield sites, raised land and landfills, mine haul roads and bulk earthworks. The principle common to all these is the reduction in the volume of air voids in the impact rolled material. However, apart from improving the relative density of the material, this has the added effect of a general reduction in the material's permeability, a factor that has been utilised in the agricultural industry.

Pinard and Ookeditse (1990) and Pinard (1999) discuss the principles of impact rollers and their use in semi-arid areas to achieve a stiffer more uniform subgrade using less water during compaction and with little control on subgrade moisture content. This is a particular feature of impact rolling attractive to its application in Australia’s agricultural sector.

Test Methods for Monitoring and Validation

Many different test methods are utilised to verify the effects of impact rolling, varying dramatically from site to site and project to project. It is considered that this variation is generally attributable to a combination of the designer’s and/or geotechnical engineer’s preferences and experience with impact rolling, the readily available test equipment, budget constraints, the site’s location and/or particular site conditions. Table A-1 in Appendix A lists the tests encountered in the author’s experience.

The test method selected for a particular site may need to take account of ground conditions (e.g. fine-grained natural soils or miscellaneous fill with large inclusions), the proposed end use or specification requirement set by the engineer, and the actual objectives of the impact rolling. At present, some combination of input from the client, design engineer, contractor, geotechnical engineer and impact roller supplier probably determines the testing regime. Appropriate testing protocols, before, during and after impact rolling, related to a range of end uses, site conditions and engineering specifications, combined with the advantages and disadvantages of testing equipment, is an area that the author considers warrants further research.

In the agricultural sector, while simple settlement monitoring might be useful, it is considered that a combination of mechanical (classification) tests and field infiltration tests will assist with confirmation of the effectiveness of the treatment, as well as enhancing the understanding of the mechanism that is occurring. Appendix B outlines a simple infiltration test adopted by Broons.

AGRICULTURAL APPLICATIONS

For more than 10 years, impact rollers have been used for the treatment of water storages and channels in NSW and Queensland, particularly in cotton growing areas, as illustrated in Figure 2.

Figure 2. Impact rolling water storage base, NSW.

The first known application of impact rolling in the agricultural sector in Australia was in 1992 in north-western NSW. Problems with leakage from a cotton water storage were attributed by Fitzhardinge (1992) to defects in the soil mass. Such defects might arise from the entry of sand blown into cracks in the clay during the dry season, resulting in localised high vertical permeability, from remnant root holes or animal burrows, or from discontinuity of the clay which generally overlay permeable soils. Dowling (1994) reports anecdotal evidence of the successful application of the impact roller to reduce leakage from water storages in the early 1990s.

Humphreys, et al (1998) describe trials with 3-, 4- and 5-sided machines to assess the potential to seal highly permeable areas in rice paddocks. They reported that the soil moisture content at the time of rolling had a significant effect, with reductions in infiltration rate evident after only 3 to 6 passes in some cases. The authors also discuss the effects on soil structure due to impact rolling. While acknowledging the potential for impact rolling to greatly reduce groundwater recharge from leaky areas, the authors called for further studies.

Auzins (1998) carried out a research project with field trials at a property in NSW, and Auzins and Southcott (1999) describe the results of this research into minimising water loss through impact rolling. They concluded that water seepage could be reduced in this manner, although improvements were not uniform, reflecting variations in soil type and moisture conditions. They called for improvements in the guidelines for the use of impact rollers for this purpose and the need for routine testing.

Akbar (2002) describes trials involving various compaction units and different field and laboratory test methods. Overall, he concluded that seepage can be significantly reduced in channels and drains by surface treatment. The 4-sided impact roller was found to be better suited to the confined conditions in channels and on banks due to its mobility and smaller turning circle than the self-propelled 3- and 5-sided units, and impact rollers, in general, were far more efficient for compaction than using a tracked excavator.

CASE STUDIES

In 2000, Clyde Agriculture conducted infiltration tests in conjunction with impact rolling at one of their cotton water storages near Bourke, NSW. The procedure adopted followed the principle of the double ring infiltration test, with 1m diameter metal rings embedded within a 5m square pond, the fall in water level being measured within the ring. Table 1 presents the infiltration rates inferred from the graphs provided by Clyde Agriculture.

Table 1. Infiltration Rates, Clyde Agriculture, 2000.

Number of passes of impact roller	**0**	**6**	**12**
Inferred infiltration rate (mm/day)	0.30	0.21	0.05

The data reflect a significant improvement after 12 passes of the impact roller, although less evident after 6 passes. This limited data set appears to support the anecdotal evidence of the efficacy of impact rolling.

Figure 3 shows a 4-sided impact roller working on a channel bank. In conjunction with channel bank improvement works in 2001, Murrumbidgee Irrigation at Leeton commissioned field density tests before and after impact rolling. Improvements in the in situ relative density, were apparent, as can be seen in their data, summarised in Table 2 as a percentage of Standard compaction.

Table 2. Field Density Results, Murrumbidgee Irrigation, 2001.

Percent compaction	**Before rolling**	**After rolling**
At the surface	91.0%	-
At a depth of 500mm	-	97.5%
At a depth of 1600mm	99.0%	99.5%

Figure 3. Improvement works on channel banks, NSW.

Broons has recently undertaken a series of infiltration tests in conjunction with channel improvement works carried out for Marthaguy Irrigation in NSW. The channel bank comprises silty clay and rises approximately 1m above the surrounding ground. The method outlined in Appendix B was utilised and the results are summarised in Table 4 for tests undertaken approximately 100mm below the top of the bank.

Table 4. Infiltration Rates, Marthaguy Irrigation, 2003.

Number of passes of impact roller	**0**	**5**
Infiltration rate (mm/hour)	210	No infiltration measurable after 1 hour

The test would appear to be too insensitive in very clayey soil for a short-term measurement once the soil has been compacted. However, the results are indicative of a significant reduction in infiltration rate after relatively few passes of the impact roller. On an adjacent section of channel bank, the settlement was measured after 9 passes, and an average indentation of 175mm was evident below the impact roller drum path.

These previously unreported case studies illustrate the positive effects of impact rolling. Reviewed in conjunction with the other referenced work (including Akbar 2002, Auzins and Southcott 1999, and Humphreys et al 1998), and considering the importance of water in the Australia environment and economy, impact rolling would seem to have a significant potential, through wider application, to further reduce agricultural water loss.

CONCLUSIONS & RECOMMENDATIONS

Impact Rolling has been utilised in Australia for nearly 20 years, and it has been shown to be of benefit to the agricultural sector for more than ten years. Impact Rolling improves the sustainability of high water-usage applications, such as in the rice and cotton industries, as demonstrated through the reduction in leakage resulting from treatment of water storage floors, channel banks and growth paddocks. Apart from cost savings, wider environmental benefits are also anticipated, including groundwater quality and soil salinity aspects.

It is considered that further research is warranted into the various applications that may be suited to impact rolling, along with the review of a testing regime appropriate to such applications. In particular, a need has been identified for further research into the application of the impact roller in the agricultural sector. A better understanding of the mechanisms of impact rolling in an agricultural setting and the development of appropriately simple field tests should demonstrate the viability of the system. The resulting benefits to industry and the environment through the use of impact rolling to reduce water losses in the agricultural sector will enhance the sustainability and engender public support.

ACKNOWLEDGEMENTS

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APPENDIX A - TEST METHODS USED TO VERIFY EFFECTS OF IMPACT ROLLING

Table A-1 lists the tests encountered in the author's experience to monitor or validate impact roller projects.

Table A-1. Impact Roller Monitoring and Verification Test Methods.

Category	**Description**	**Comments**
Classification	Particle size distribution, Atterberg Limits, Emerson dispersion	Wide application, but mechanical tests are generally not suitable for miscellaneous fill with large particle sizes
Continuous probe	Dynamic cone penetrometer (DCP), electrical friction-cone (CPT)	Provide output that may be correlated with CBR and strength
Earthworks	Field density, moisture content, laboratory compaction (MDD, OMC) and California Bearing Ratio (CBR)	Roads and general earthworks; tests represent a very small proportion of the material treated
Geophysical	Continuous surface wave	Highly specialised equipment and interpretation
Ground response	Clegg Hammer, continuous deceleration measurements	Results indicative of ground response, inconsistent correlation with engineering parameters
Permeability	Permeability tests, infiltration tests	Useful in the agricultural sector, some tests can be difficult to perform
Settlement	Precise measurement of ground deformation	Simple and effective means of quantifying impact roller effect
Strength	Falling Weight Deflectometer, static and dynamic plate load tests	Specialised tests: produce load-deflection characteristics and soil modulus values

APPENDIX B - DOUBLE RING INFILTRATION TEST METHOD

The following test method has been adapted by Broons from Irrigation Water Management: Irrigation Methods Training Manual No 5 Annex 2 "Infiltration rate and infiltration test", Food and Agriculture Organization of the United Nations (http://www.fao.org/docrep/S8684E/s8684e00.htm). Reference has also been made to ASTM D 5093-02 "Standard Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer with a Sealed-Inner Ring". The equipment utilised by Broons is illustrated in Figure B-1.

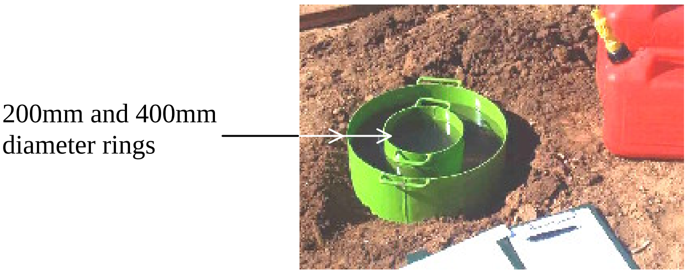

Figure B-1. Double ring infiltration test equipment.

The test is carried out as follows:

1. Excavate to below the disturbed zone (which may be approximately 200mm after impact rolling).
2. Drive the two rings at leat 50mm into the ground, leaving the rings at least 100mm above the ground.
3. Place coarse cloth material (e.g. hessian, geotextile) inside the inner ring to protect the ground surface during the addition of water.
4. Fill the outer ring with water to approximately 100mm above the ground. Then start the test by filling the inner ring to approximately 100mm above the ground. This is to be done quickly.
5. Record the water level on the measuring tape and the time when the test begins.
6. After 1-2 minutes, record the water level and time. Add water to approximately restore the original level. Maintain the water level in the outer ring similar to the inner ring.
7. Continue in this manner until the drop in water level is the same over the same time interval, increasing the time between readings as the test progresses.
8. The data may be plotted on a graph so as to compute the infiltration rate, which is the steady state drop in water level per unit of time.