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Application of water medication technology in the Australian beef industry

A review of literature

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1 Introduction

The Australian beef industry is primarily a grass-based industry, utilising a wide range of native and improved pasture systems, which vary greatly across the country. In 2001-2002, grassfed beef made up nearly 70% of total beef production in Australia (Gleeson et al 2003). However regardless of location, seasonal variations in rainfall distribution often result in significant fluctuations in pasture quality and quantity, which impact on a range of production traits including growth, fertility and survival (Entwistle, 1983; Winks, 1990; McCosker et al, 1991; Dixon et al 1996). In addition, low soil fertility in some regions influences pasture quality and animal nutrient status (Miller et al, 1997), further influencing cattle performance.

Optimising production requires that the physiological needs of the animal are matched with available nutrients, and for most environments and regions, particularly in Northern Australia, there is a seasonal imbalance between supply and demand. Supplementary feeding represents one, but not the only option, available to bridge the gap between nutrient supply and demand, since there are also a range of other management strategies (Holroyd et al 1988; McCosker et al 1991; Fordyce and Entwistle, 1992; Braithwate and de Witte, 1999) which can be used in breeder herds to minimise the need for additional nutrient inputs.

Nutritional supplementation to enhance production or to supply specific limiting nutrients is a widely used management tool across broad sections of the industry and the literature on supplements and traditional supplementation techniques and strategies is voluminous (eg Winks, 1984; McLennan et al 1981,1991; Lindsay, 1984; Dixon et al 1996, Leng, 2003). Common supplement delivery methods include loose dry mixes, incorporation of supplements in energy sources such as molasses (eg urea-molasses-M8U) and compressed blocks incorporating various nutrients with salt, molasses and binding agents. However, in some of these traditional supplementation systems, particularly those containing non-protein nitrogen (NPN, usually urea) and phosphorous (P) sources, irregular and variable intakes of supplements have often occurred where some animals over-consume, some under-consume, and others reject the supplement, leading to considerable variations in production responses (Entwistle and Knights, 1974; Nolan et a,l 1974; Dove, 1984; McLennan et al, 1981, 1991; Dixon et al, 1997). This variability is caused by a number of factors, including animal behaviour effects such as previous exposure to supplements, dominance and temperament, and location of blocks in a grazing area (Petherick et al, 1998). Supplement factors including poor palatability, and/or poor attractiveness of some supplement ingredients for example phosphorus, and in the case of compressed blocks, lick block hardness can also influence acceptability and levels of intake (McLennan et al, 1981). These restricted intake problems can be severe under some extensive grazing situations, leading to poor efficiency of utilisation, lower than anticipated production responses and higher costs.

During the early 1980s research workers and producers began to recognise that variations in supplement responses were causing inefficiencies and negative economic impacts on productivity. This led to an examination of alternative supplementation strategies, and water medication strategies[1] were examined in several studies (Stephenson et al, 1981, Stephenson, 1983; Stephenson and Hopkins, 1985) where supplements (particularly NPN) were provided through the water. The rationale for this approach was that all animals must consume water as

[1] Water medication refers to the supply of specific nutritional supplements using water as the vehicle. It does not refer to the colloquial definition of medication, which is the use of a healing agent for disease.

an obligatory physiological function, and since ruminants of a particular physiological state will drink according to their metabolic requirements (McFarlane and Howard, 1974), they could be supplied with and receive nutrients in solution at levels proportional to their water intake. This rationale was also based on the joint premises that alternative water sources would not be available; that there would be only small variation in water intake between individual animals of similar type or status (and hence only small variation in nutrient intake received in the water); and that soluble and safe nutrient sources would be available (Stephenson 1983; Stephenson and Hopkins, 1985).

Thus, central to the concept of water medication technology is the compulsory and relatively uniform intake of a soluble and safe medicament from a controlled facility that provides the only water source for grazing animals.

This review is not a traditional scientific literature review, but rather a combination of relevant published information together with considerable anecdotal information from producers using water medication. This approach has been adopted because of the relative paucity of published information on the application of and responses to water medication technology.

2 Water medication technology

In a number of areas of plant agriculture, including viticulture and hydroponic systems, incorporation of nutrients into irrigation systems has been practised for many years. Similarly in intensive animal industries such as the pig and poultry industries, water medication has been widely used not only for nutrient supply but also for supplying a range of animal health products. An extensive search of the world literature indicates that it is primarily in the Australian beef and sheep industries that water medication technology has been widely used, and there are few references to it's use in grazing livestock industries in other countries. There is also a problem with critically assessing the technology, as there is a paucity of objective Australian and international information on responses to this form of supplementation.

While supplementing cattle and sheep via the water using NPN and P sources, and other substances has been recognised as an alternative, cheap and attractive strategy for over 20 years, the adoption of this technology, where it can be applied, has not been widespread. Most early dispensers worked on the mechanical principle of a tipping bucket, where supplement or additive flow to a bucket was at a rate controlled by water flow into the trough. At a certain mass the bucket tipped, discharging the nutrient into the trough, the other bucket commenced filling and the cycle of filling and discharge continued. Whilst many claims were made regarding efficiency and safety of these devices, experience indicated that they were inherently unreliable, with a high risk factor. A number of these earlier mechanical dispensers had frequent malfunctions, sometimes resulting in livestock mortalities due to excessive NPN intake. In addition, critical questions of interactions of water quality and medicaments were not always recognised and the use of unsuitable medicaments often created problems. The end result of this complex of problems was that many producers developed negative attitudes to water medication, which resulted in rejection by some and non-adoption by other producers of the technology.

More recently, technological improvements have been incorporated into medicators, resulting in a wider interest in and adoption of the technology. Currently however, most use of this improved technology has been in the extensive Northern Australian cattle industry (Entwistle and Jephcott, unpublished).

There are currently a number of water medication systems available commercially which are either electronic (eg NORPRIM®; NUTRIDOSE®) or water pressure powered (eg DOSATRON®) proportional dispensers which can be adjusted to inject a range of substances into livestock drinking water. These units are available in a range of types and sizes to suit particular applications or particular systems (eg high/low pressure systems), and most have some built-in safety features to minimise toxicity risks associated with accidental high intakes of potentially hazardous substances.

The modes of action of water medicators are discussed briefly below. It is not the purpose of this review however to compare and contrast the costs, performance and efficiency of these different systems. It should be pointed out that, without in any way disparaging the technology, and recognising that a number of safety devices are built into all newer medicator systems, there remain potential hazards in using water medication for dispensing NPN sources such as urea which are toxic to cattle at high levels. These hazards may not only be associated with system malfunctions, but can also occur due to human error (poor monitoring and maintenance, incorrect supplement concentrate mixtures, poorly prepared concentrates), excessive water intakes (and hence NPN intakes) under ambient temperature extremes, incorrect installations of medicators or combinations of these factors.

Clearly the successful use of water medication technology requires a good appreciation and understanding of nutritional principles, and of the timing and levels of supplementation to achieve optimal responses. Water facility infrastructure of a high standard and requiring significant capital investments is needed. A high level of management expertise, an understanding of the underlying technology, and a commitment to continual maintenance and monitoring of the system are other prerequisites if this technology is to be successfully applied. A good understanding of water quality issues, and of the effects of interactions of minerals in the water with those supplied in the supplement, is also essential for successful use of water medication.

3 Principles of action of currently available commercial water medicators

There are two major types of medicators currently on the market. One type is a fully electronic proportional dispenser (NORPRIM®; NUTRIDOSE®) in which a small electric pump is used to inject an adjustable amount of nutrient concentrate into the pipeline or water trough, utilising a flow sensor or water meter which measures water in-flow in the supply line, and triggers the nutrient pump. Power is usually supplied by a 12 volt DC battery, often recharged by a solar panel or in some cases from a mains supply battery charger. Units are supplied in different sizes dependent on flow rates, water pressure and numbers of animals being supplied. Water consumption is measured (and nutrient intakes adjusted accordingly) with either a mechanical water meter or electronic turbine flow sensor. These units are equipped with several safety features including electronic cut-out valves and an anti-siphon device to minimise possible urea toxicity hazards due to over-supply of concentrate (Wood 2002, 2003; Peart 2001). In more advanced versions, provision is now being made for electronic circuitry to link with telemetry equipment to activate alarm systems in the event of malfunction and to enable remote sensing of trough and tank water levels, medicator operations and nutrient concentrations in the water trough.

Several types of water pressure powered proportional medicators are on the market, of which the most common is the Dosatron ®, though some Dosomatic ® units are still in use. These units originated in France and were originally developed for plant agriculture and for use in intensive animal industries. The potential application of these, and other medicators used in hydroponic agriculture in Europe, for extensive beef production in Australia is currently (2004) being re-examined by Mr Micheal McKellar, a Western Queensland beef producer and holder of a Nuffield Scholarship.

These types of units have been widely used for grazing livestock in Australia and are still the preferred choice of a minority of users concerned at the possibility of electronic breakdowns in other types of units. The units utilise a water-driven reciprocating piston to inject the concentrate solution into the water line, proportional injection of the nutrient concentrate being governed by flow rate of water into the pipeline or trough. Although both high and low-pressure units are available, they still require a pressure head for operation. Safety devices including an in-line filter on the inlet side and an anti-siphon device are usually installed. There have been some reports of malfunction due to excessive wear of the plastic cylinders and piston and problems with corroding springs as a result of sediments in the water, though stainless steel pistons and cylinders, and extensive filter systems that are regularly cleaned are reported to minimise this problem. Progressive deterioration of the plastic casing of the medicator when exposed to long periods of solar radiation has also been reported, though this can be minimised through protective shading of the units. Dosatron® units require a high operating head, so are not appropriate for all watering systems, or where water consumption is low. Due to the high maintenance required and other problems mentioned, Dosatron® units have largely been replaced by the much improved electronic proportional dispensers.

Regardless of the type of unit, there are potential problems with the corrosive nature of some highly concentrated nutrient solutions used for supplementing livestock. Solutions containing urea, sulphur and some phosphorous sources can be extremely corrosive under some conditions, particularly when prepared with poor quality water. Corrosion damage to metal pipes and fittings and some pump components can occur, leading to unit malfunctions. Polythene rather than metal pipes and fittings are recommended, and an in-line filter on the inlet line from the concentrate tank is usually installed to remove sediment and crystals from the concentrate before it enters the pump. Concentrate solutions remaining in the lines and pump at the end of the season may sometimes crystallise, causing pump damage, and pre-shutdown flushing of lines and pumps with fresh water is a recommended maintenance procedure. Similarly, polythene concentrate tanks, rather than plastic, fibreglass or metal tanks are usually recommended, both to minimise corrosive effects and also to minimise UV light penetration which can encourage algal growth particularly in concentrate solutions containing phosphorus (P) (Hirst, 1996). The electronic units, NORPRIM® and NUTRIDOSE®, are stainless steel sealed units designed to prevent nutrient solutions leaking into the electronic components. The manufacturers also provide considerable warnings and training on the dangers of allowing nutrient solutions or ammonia fumes contaminating the units while reading unit outputs or adjusting the controls (M Peart,pers comm).

4 Water intake

Animals gain water in three ways: by drinking; from water in feed; and as metabolic water from oxidation of dietary nutrients and of body tissues. For the efficient operation of water medication technology, a knowledge of water intakes of cattle is required in order to adjust supplement concentrations to ensure optimal supplementation intakes are achieved. There is however limited critical information on levels of water intake in beef cattle under Australian grazing conditions. Animal factors such as weight, physiological status, genotype and degree of stress, as well as a range of environmental, seasonal and topographical factors (ambient temperature, humidity, wind speed and direction, pasture dry matter content, water quality, distance between water points), are recognised to affect daily water intake (McFarlane and Howard, 1974; T Mott pers comm). However the magnitude of these effects is not well documented. A general and widely used empirical value has been an intake approximating 10% of bodyweight. Thus for a 450kg animal an average daily intake of 45L has been widely used as a basis for calculating livestock water needs (QDPI, 1982). Sheep and cattle drink about 4L/d/kg dry matter (DM) consumed (NRC, 1996) which gives a theoretical daily water intake of 45-50L for a 450kg steer, similar to the estimate above, though the between animal variation in water intake is more difficult to predict. McLennan *et al* (1991) found large coefficients of variation (up to 55%) for between year and between treatment intakes of water in weaner heifers in north Queensland. In contrast, in sheep in semi-arid Queensland, between-animal coefficients of variation in water intake were only 9-15% (Stephenson and Hopkins, 1985).

However both anecdotal and published information indicates that the range of intakes is considerably wider than indicated above. Luke (1987) calculated seasonal variations in water consumption data for a number of locations in the pastoral zones of Western Australia. On an Adult Equivalent (AE = 400kg steer) basis, he estimated that across these zones daily consumption rates ranged from 9 to 53L/AE. In north Queensland, McLennan *et al* (1991) found daily water intakes to vary between years, ranging from 10 to 13L for similar size weaners. In Victoria, Birrell (1992) reported seasonal increases in water consumption of cattle during the summer in cattle under drought feeding conditions, though in 300kg steers average daily intakes of about 14L were lower than the above estimates would suggest as being normal. In a study in the USA, Winchester and Morris (1956) reported daily intakes in lactating beef cows ranging from 62 to 72L when average maximum temperatures were between 20 - 32^{o}C, with comparable figures for 450kg steers being from 29 to 78L. There is anecdotal evidence from central Queensland (J. McTaggart, pers comm.) that daily water intakes of lactating cows during periods of high ambient temperatures (> 42^{o}C) can reach more than 100L, while in the arid Alice Springs area, daily water intakes for breeding females have been estimated to range from 35-55L depending on seasonal conditions (C.Nott, pers comm.).

Water quality also has a significant effect on daily water intake (McCosker 2000; Carson, 2000). On more than one property in central Queensland where breeders were consuming poor quality water, daily intakes during winter months dropped to as low as 9 to 12L, but improved to about 25L when water quality was modified and improved (S. Waterton; R Thieme, pers comm). These low intakes would probably have had a significant effect on levels of production. It therefore follows that for efficient use of water medication technology, good data on water intakes is essential and monitoring of intakes should be an integral part of the use and management of this technology.

Despite some anecdotal evidence, the impact of water quality on water intake, on feed intake and hence on production is not well understood, nor is there good documentation of these interrelationships. These are areas that require further investigation, given the wide variations in water quality that have been recorded across the pastoral areas of Australia (Hart, 1974).

Other confounding factors in determining water intake of cattle in many extensive pastoral regions, where controlled waters are the only water sources available, include accurate determination of numbers watering at a trough, since some animals may have been missed at a muster, and consumption of water by unknown numbers of feral animals (goats, donkeys, brumbies, camels) and native wildlife using these water sources. In addition, on many properties, one bore, medicator unit and water flow meter often supplies several paddocks, which may contain different classes of livestock, on pastures that may differ in type and quality. On others, using an interconnected water grid system, a trough may be supplied by several bores equipped with medicator units (A. Lord; D. Makim, pers comm). In these situations it is very difficult to get good estimates of water intake.

In summary, the available data, and experience of many cattle producers suggests that average daily intakes on reasonable quality water range around 45-55L for mature animals weighing about 450kg. However these estimates should be increased by at least 25% for lactating cows, and for periods when high temperatures occur.

5 Water quality issues

While water quality is an identified problem in some areas, and requires further definition work, the more important step is in finding solutions to improve quality, thereby enhancing water intake, improving the efficiency of water medication and improving animal performance.

A growing body of evidence, much of it again anecdotal, suggests that interactions of nutrient components with water constituents can have significant effects on water intake. However, more critical information on relationships of water quality, water intake and productivity has been difficult to locate, though the authors are aware of some current work in the Northern Territory (S. Petty, pers comm.) examining these relationships.

There are a number of measurable water quality parameters of importance, of which the most important are pH, total dissolved solids (TDS), electrical conductivity (EC) that is a measure of TDS, and total alkalinity (TA). Satisfactory values for these parameters can be summarised as follows: pH 6-8; EC <15dS/cm; TDS <10,000 mg/L. In addition, water calcium (Ca) levels can be important in many circumstances, because of impacts on pH levels and because of Ca ion precipitation in piping and fittings. This causes excessive scale (calcium carbonate) formation and deposition which can reduce flow rates and which can sometimes interfere with float valve and water medicator function. Where both Ca and magnesium (Mg) levels are high, use of P supplements may result in formation of calcium and magnesium ammonium phosphates, both of which are insoluble and which can precipitate out of solution, flocculate in water or which can form a hard scale in pipelines and fittings. Addition of acids usually overcomes these problems and when waters are acidic rather than alkaline these phosphates are soluble and scale problems do not occur. However, there may be some loss of added P when precipitation problems do occur.

There is also considerable anecdotal evidence and some limited monitoring data to indicate that for some water sources there is a seasonal variation in quality. For example, Savage (2003) monitored water quality from sub-artesian bores on the Barkly Tablelands of the Northern Territory and found a generally consistent pattern of small declines in pH values and EC measures between early dry–end of dry season samples, though P and total TA values increased during this time. However seasonal changes in water quality are poorly understood and their possible effects on intake and responses to water medication need to be better defined.

There are experimental and anecdotal reports of urea loss associated with alkaline waters high in Ca, and where calcium carbonate deposition is occurring (Hirst, 1996). Whilst the exact chemical changes occurring cannot be well defined, it is probable that urea is being hydrolysed into ammonia and carbon dioxide, the latter binding with high levels of Ca ions to cause precipitation and deposition of calcium carbonate. A report by Andison (1994) indicated that at Katherine in the Northern Territory, where alkaline water was used, there was a loss of about 85% of the urea added to a concentrate tank over a 24 week period, with evidence that nitrogen concentrations were higher at the bottom than the top of the tank, indicating a concentration gradient effect which potentially could have negative impacts on livestock. While concentrate solutions would normally not be stored for this length of time, they often are for shorter periods when medicators are turned off during the wet season because other water sources are available. Hence where water quality is a problem, because of likely product loss, large volumes of concentrate should not be left for long periods. Additionally, because of possible concentration gradients in the tank, frequent and thorough mixing of the concentrate should be a routine. One producer in the Alice Springs area has minimised this problem by mixing the concentrate using high quality water from a particular bore and then refilling individual bore concentrate tanks using a bulk tanker, thereby minimising urea hydrolysis and volatilisation (C. Nott, pers comm.). In water with a very high pH and high EC, there is evidence that urea can hydrolyse during short storage periods and during transport over medium to long delivery lines (>3km) (R Mackenzie; M. Peart; D Makim, pers comms).

General recommendations for using water medication have been for water quality to be checked before installation and to routinely monitor water pH, though recent evidence (Entwistle and Jephcott, unpublished) indicates that this is not always a routine procedure. There are now a number of cheap, reliable and effective portable pH meters available, that are suitable for routine monitoring. The ideal pH for good quality stock water, without medication, is in the range 6.9 - 8.0, though there are anecdotal reports of water with pH up to 8.2 still being suitable. As mentioned, a major problem with adding nutritional supplements to alkaline waters (>pH 7.2) is volatilisation and/or hydrolysis of urea to ammonia either in the concentrate tank or at the trough, with consequent loss of product. Ammonia levels, if at sufficiently high levels at the trough, will inhibit water consumption by cattle (Hirst, 1996).

The presence of high levels of iron, magnesium and sulphur dependent anaerobic bacteria can also depress water intakes. These bacteria can be reduced or eliminated by oxidizing the water through aeration. Aerators are available for farm water storage tanks and larger water driven aerators (venturi effect) for turkey nest tanks (I Gundrill pers comm). Other simple tools for aerating water include taking the water from the top of the turkey nest and allowing the water entering the trough to be exposed to air rather than entering below the trough water level.

Variations in the type and quality of supplements used can also have an effect on interactions with water of poorer quality. For example, fertiliser grade[2] (rather than technical grade) mono ammonium phosphorous (MAP) will frequently flocculate or form sediments and scale in pipelines when used with alkaline or high Ca or Mg waters. Fertiliser grade MAP also frequently contains high levels of both cadmium

[2] Fertilizer grade material usually has a coarser granular structure, is usually less soluble and in some cases may have more contaminants than technical grades of the same product.

and fluorine, both of which are potentially hazardous to cattle when used for long periods. Similarly in some poor quality waters, fertilizer grade ammonium sulphate (AS) used as a sulphur (S) source, has been reported to precipitate, forming a sludge that can interfere with medicator pump function, or increase wear on moving parts.

The importance of determining and monitoring water quality before and during the use of water medication technology cannot be over-emphasised, since water quality issues may influence the success or otherwise of this technology.

6 Mechanisms for improving water quality

There have been a number of approaches to improving water quality in conjunction with the use of water medicators. For highly alkaline waters (pH> 8.0–8.2) acidification using acids (eg hydrochloric, phosphoric, urea phosphate) has been used with the added advantage that calcium carbonate and other deposits in pipelines are reduced. Several types of acid injector pumps are on the market and have been used successfully for water quality modification. Over the past few years, magnet technology has been recommended and used to enhance water quality (eg McCosker, 2000). Anecdotal comments suggest that while this technology has a reasonably good track record, it has proved ineffective in some situations. There is limited scientific data on the possible mode of action and efficacy of magnets (Fluid Reactor ®) applied to water pipelines. However proponents have suggested that the high performance electro-magnetic energy enhances anion-cation exchange, transmits positive energy to the water, reduces surface tension of water molecules and reduce hardness by reducing calcium crystallisation and scale build up (Gundrill, 2000). It is also suggested that application of magnets has in some situations reduced iron and magnesium dependent anaerobic bacterial growth and algal growth in water to which nutrients have been added, perhaps through effects of electro-magnetic radiation on cellular structures.

However, the effects of magnets in changing water pH generally appear to be small or non-existent, though according to the manufacturer and supplier of magnets such as the Fluid Reactor ®, this is not the role of magnet technology (Gundrill, 2000). In summary, while magnet technology is not a cure for all water problems it may be effective in some situations. As with all untested technology however, a better understanding and definition of the principles involved would lead to more efficient application of this somewhat expensive, and controversial technique.

A number of other devices are on the market that are claimed to improve water quality. Some, such as the Water Wizard and Waterpure, are claimed to induce a vortex type effect on flow patterns of water in a pipeline, reducing ion precipitation, and build up of scale, thus improving flow efficiency. Others, such as the CALCLEAR® water conditioner, use ionisation by electromagnetic induction which is claimed to change the ability of calcium ions to crystallise, thereby minimising scale formation. Again, anecdotal evidence suggests that these and other technologies may work in some, but not all, situations to enhance water quality for cattle.

Given the variations in sources and quality of water used by cattle, the influence of water intake levels on productivity, the interactions of water quality parameters with nutrient solubility and stability, and thus the effectiveness of water medication technology, there is a strong case for some additional research in these areas. A starting point in any further research would be a review of recent Bureau of Rural Science publications (2000 – 2003) on water quality investigations in rural areas across Australia, followed by an independent review of the modes of action and effectiveness of commercially available water quality modification devices. Other aspects which could be explored include seasonal and regional variations in important water quality parameters including pH, EC, TA and ionic concentrations; defining levels of water quality parameters which may impact on water intake; definition of the circumstances where waters of different quality interact adversely with supplements commonly used in water medication applications; an evaluation of the suitability of a range of available supplements for different quality waters, and either documentation from existing sources or additional mapping of bore water quality throughout Northern Australia. Information should include geographical and hydrological effects and documentation of important water quality parameters of various sub-artesian and artesian streams. Some definition of these issues would be a valuable tool for current and future users of water medication technology.

7 Supplements used for water medication

The primary use of water medication technology to date for grazing cattle has been the provision of N, P and S sources. In some areas with identified trace mineral deficiencies, water medication has been used to provide essential trace minerals such as copper, cobalt, selenium and zinc. Water medication has also been used to provide electrolytes and glucose to cattle pre transport to minimise road and sea transport stress (Phillips 1997), and pre slaughter to enhance meat quality (Roberts, 1982), and to reduce stress and subsequent disease outbreaks in weaners on northern properties (A. Henderson, M. Perkins, pers comms). There are also anecdotal reports of other substances such as seaweed extract, bloat control oils, other soluble energy sources and some organic anthelmintics being supplied through the technology. Earlier work (Stephenson and Hopkins, 1985) suggested the use of water medication for provision of internal and external parasitic control products but little further work appears to have been done on these issues, though a range of animal health products are widely used by intensive monogastric industries using water medicators.

8 Nitrogen and sulphur sources

By far the most common NPN source used for water medication has been urea, usually mixed with ammonium sulphate to provide a S source (Winks *et al* 1979; McLennan *et al* 1981; 1991; McCosker *et al* 1991; Dixon 1994; Hirst, 1996). Urea is rapidly hydrolysed to ammonia in the rumen, which is then available for microbial synthesis of protein, though the effectiveness of urea as a supplement is limited by available carbohydrate (Nolan and Leng, 1972). Urea improves performance through increasing intake; increasing intake effectively increases stocking rate with additional pressures on pastures. Whilst this may not be a problem in those areas where pasture DM availability is generally not limiting, (though seasonal pasture quality may vary), lack of recognition of this scenario has resulted in over-stocking problems and reduced performance in many areas of Northern Australia (Nutrition Edge, 2003).

The optimal amount of urea needed by cattle grazing dry season pastures has been calculated from numerous experiments in both temperate and tropical regions, and ranges from about 30g/h/d for weaners and yearlings to 45-60g/h/d for lactating females (Winks *et al* 1979, Dixon 1994). There appear to have been few studies on optimal levels of urea provided through water medicators, and urea intake levels determined from other supplement regimes (eg Winks *et al,* 1979; McLennan *et al* 1981) have been generally adopted in most trials evaluating the technology (McLennan *et al* 1989; Bawden 1997, 1998; Hill 2003). However, current work on the Barkly Tablelands (S. Petty, pers comm.) is examining responses to a wider range of urea levels in cattle supplemented via water medicators.

The potential hazards of urea toxicity are well recognised and mortalities due either to medicator malfunction, human error or poor management (eg access of naive or thirsty cattle to water containing above about 0.2% urea (2g/L) have occurred (Holm *et al*, 1981; Winks, 1984; McLennan *et al* 1989; Hirst, 1996; Entwistle and Jephcott, unpublished). Some early work (Winks et al 1979) examined production responses to increasing levels of urea in molasses mixes, and attempted to define levels likely to result in toxicity. However there do not appear to have been any similar dose response or toxicity studies involving urea dispensed in water, though some work is currently underway (S.Petty, pers comm.). There are also suggestions of a depressed water and feed intake when urea concentrations exceed 2g/L, particularly on alkaline waters (Holm *et al*, 1981). Low biuret, stock feed grade urea (rather than fertiliser grade) is recommended, to minimise precipitation and sedimentation when using poor quality water (Hirst, 1996). As mentioned previously, some experimental work in the Northern Territory (Andison, 1994) suggested some vertical layering of urea concentrations, though other experience suggests that provided thorough mixing and agitation of the concentrate solution is achieved (using a pump or agitator) this is not a problem. A number of users of the technology make a practice of stirring or recirculating concentrate tanks on each occasion that waters and medicators are checked (Entwistle and Jephcott, unpublished). Urea hydrolysis and layering can also be prevented or reduced by only mixing enough nutrient solution to supply requirements for 7 to 10 days (M Peart pers comm).

Several methods of testing urea concentrations in the trough water are now becoming available, including a simplified test kit (U-100 & U-100N - Gundrill Trading), similar to a pool chlorine test kit, for determining urea concentrations by a colour reaction. A more sophisticated testing system now under development involves an electronic monitoring probe within the water trough to detect concentrations of a marker added to urea, by determining conductivity before and after the urea solution is injected. The probe activates a safety cut-out system on the water medicator if needed (Wood, 2003).

There are occasional reports of high ammonia levels being detected at water troughs with either refusal of water or reduced intakes. Dolinski (1995) reported that this problem occurred when urea supplemented water was not consumed after rain when alternative surface water was available, and the urea containing water remained in the trough. Either accidental high concentrations of urea, or hydrolysis of urea because of interactions with some components of poor quality water are causes of high ammonia levels, and caution is needed re potential toxicity problems when this situation occurs. Algal growth has also been reported on occasions, probably because of enhanced nutrient status (N + P) in medicated water, particularly when this water is exposed to sunlight. Chelated copper compounds and swimming pool algacides have been used for control, though these increase overall costs of the technology. One novel approach reported recently by a producer was the use of small native fish to control algal growth in storage tanks and troughs (M. House, pers comm).

The most commonly used S source is technical grade ammonium sulphate (AS), though some other products are available such as GRAN AM®, a fertiliser grade granulated AS source containing an appreciable amount of N (Hirst, 1996).). In poor quality waters it is important that technical grade rather than fertiliser grade AS is used to minimise precipitation problems (T Wood, pers comm.). Sulphur is usually added to provide a N:S ratio of about 10:1, though there is some evidence that the optimal ratio can range from 5:1 to 20:1 (Underwood and Suttle, 1999). Ammonium sulphate, though highly soluble, can occasionally form precipitates in poor quality waters, and thorough and frequent mixing is needed in these situations. In one study (Holm *et al*, 1981) water intakes were reduced when AS was added to drinking water, but this may have reflected depressed intakes due to concurrent high urea levels also being fed. In contrast McLennan *et al* (1991) found that there were no significant differences in water consumption of heifers when AS levels were up to 0.6g/L.

Whilst most producers use on-site prepared mixes of urea, with a sulphur source plus any other component such as a P source, (Adams and Savage 1996; Anon, 1997), prepared mixes are increasingly becoming available. These prepared mixes have the advantage of similar or marginally higher cost but lower labour requirements, with the added advantage of minimising operator error in mixing. There are also several liquid forms of N and S supplements available, though there is no critical information on the efficacy of these products. Anecdotal evidence suggests that they are suitable in some but not all situations (Entwistle and Jephcott, unpublished).

9 Phosphorous sources

Low soil and plant P status in many Australian beef cattle regions leads to problems of clinical and subclinical P deficiency with depressed levels of performance (Ternouth, 1990; Miller *et al* 1996, 1997). In these areas, supplementation using dry licks or lick blocks has been widely used over the past three decades (Winks, 1990). Levels of P available to the animal are also influenced by other factors including pasture growth stage and intake of protein and energy, while animal requirements are influenced by age, size and physiological state of the animal. A detailed discussion on P metabolism, requirements and supplementation strategies is not appropriate here and a number of extensive reviews over the past decade (Winks 1990, Ternouth 1990; Coates, 1994; McCosker and Winks 1994, Miller *et al* 1997) should be consulted to provide a good coverage of these areas.

There is general agreement that responses to P supplementation can only be expected during periods when cattle are gaining weight (Coates, 1994; Miller *et al* 1997). This is because high energy and protein intakes during the wet season allow for rapid growth and milk production, both of which require higher P intake levels. This has led to the general conclusion that P supplements need to be primarily fed to animals during the wet season (Coates, 1994), whilst during the dry season N is more likely to be limiting than P (Miller *et al* 1997).

Early work with black phosphoric acid as a P source (Playne, 1974) indicated detrimental effects on productivity, including reduced water intake, probably due to contaminants. However food grade phosphoric acid or urea phosphate fertiliser (Magnum P-44 ®) used for water acidification may not cause these problems (Hirst, 1996). Fertiliser grade mono ammonium phosphate (MAP) when added to poor quality water frequently does not dissolve completely, with sludge formation in the concentrate tank and the probability that this may interfere with dispenser function. However, technical grade MAP usually does not cause these problems (Peart, 2001).

Several other P supplements (eg rock phosphate, superphosphate, kynefos) used in dry lick formulations are not fully water soluble and should not be used in water medicators. There are also a number of other P sources on the market, both liquid and granular, that are claimed to be more effective than the sources mentioned above, though there is no good quantitative data available to substantiate these claims.

Prepared mixes containing N, P and S in appropriate proportions are now being marketed, and used by a number of producers. Provided costs are approximately the same, labour savings and potential reductions in human error in preparing concentrate mixes make these an attractive option to on-property prepared supplements. However there are again anecdotal reports of adverse reactions with some of these prepared supplements when used with some poor quality water sources (Entwistle and Jephcott, unpublished).

As mentioned earlier, algal growth in concentrate tanks and water troughs is sometimes a problem with mixtures containing N + P. Sealable polythene tanks resistant to UV radiation are preferred and storage of medicated water in either open-top or earth tanks is not recommended because of problems of algal growth. Where medicated water (at nutrient levels ready for consumption) is stored in tanks supplying a trough, closed tanks should be used to minimise algal growth and reduce potential loss of nutrients (Andison, 1994; Hirst, 1996).

Costs of supplements (N+P) provided to cattle using water medication technology are estimated to be half to one third that of traditional forms of supplementation (Bawden, 1998; Hill, 2003) though these savings have to be balanced against the capital investment of setting up water medication units. While labour savings are often cited as an advantage to the technology, these may be more imagined than real, since regular checking of bores and watering facilities and equipment still involves labour and transport cost components. However a major advantage of water medication over dry lick and compressed blocks is the reduced fuel costs and vehicle maintenance due to the significantly reduced amounts being fed (Entwistle and Jephcott unpublished). Development of more effective remote sensing equipment could result in further cost savings in transport and labour costs.

10 Water medication supplementation strategies

General recommendations have been for NPN supplements to be fed to cattle on dry season pastures low in protein (Winks et al 1979, McCosker et al 1991). While traditional approaches (based on earlier work by Winks et al 1979) have been to commence urea supplementation when faecal nitrogen levels fall below 1.3%, there are a number of unconfirmed reports from central Queensland of positive production responses to lower levels (10 – 25g) of urea when provided to cattle on high quality wet season pastures (T. McCosker, R Sparke, pers comm.). It is probable that these responses occur during the wet-dry transitional period when pasture N levels are starting to fall, rather than over all the wet season.

Though these claims have not to our knowledge been tested experimentally, there may be a case for a more detailed examination of these strategies under these more intensive conditions on expensive land carrying high quality pastures, since profitability and return on capital investment is dependent on very high levels of performance.

Some of the confusion regarding the cost benefit of feeding growing cattle with urea based supplements on highly productive pasture during the dry season is the costing of compensatory growth. Earlier trials compared the weight of controls with supplemented cattle at bullock turn-off weight. In recent years, expansion of the live export trade, increased feedlot production and increased *Bos taurus* content in many herds has resulted in lower turn-off age and weight which may reduce the cost benefit effects of compensatory growth. Some of the work supported within the Beef Cooperative Research Centre program has also shown that carcass quality is adversely affected where animals experience poor nutrition up to 240 kg liveweight (Thompson, 2002; Reverter et al, 2003).

In supplying urea via water medication, general recommendations have been to progressively increase urea intakes in order to minimise potential toxicity problems (Winks *et al*, 1979, McLennan *et al*, 1991, Hill, 2003). For lactating breeders initial daily intakes of about 10g/h have been widely used, increasing to 45–60g/h over a 2–3 week period. However, other anecdotal evidence suggests that cattle can adjust more rapidly to higher daily urea intakes, commencing at about 20g/h.

As mentioned, the accepted strategy has been to feed P supplements during the wet season (Miller *et al* 1997) though in some regions in north Australia where soil and pasture P status is very low, year round feeding of P is a normal practice (P. Finlay; W. Tomlinson pers comms; Savage, 1997). This partly reflects the fact that in some of these areas where cattle only have very low P intakes, bone chewing is common, increasing the risk of outbreaks of botulism. It is thought that P supplementation during the dry season may minimise losses due to this disease. In contrast to urea, P levels provided through a water medication unit are usually provided at constant levels, requirements for lactating cows being in the vicinity of 10g/h/d with lower levels for growing cattle. . The majority of producers in northern Australia practice continuous mating, and therefore generally have approximately 30% of their breeder herd lactating during the dry season. Where pastures are deficient in P, these lactating breeders require P supplementation during the dry season (S Jephcott, unpublished).

Trace element deficiencies, the most important of which are copper, cobalt, selenium and zinc, are rarely the first limiting nutrients for cattle grazing pastures in most areas of Northern Australia, other than in some parts of coastal NW Western Australia. These micro-nutrients are most likely to be limiting in situations when energy intake is high, and N and P status is adequate. Where trace minerals are being provided general practice has been to supply these on a year round basis (Underwood and Suttle, 1999), though it is likely that needs are greatest when pastures are of highest quality. A number of proprietary supplement products sold for use in water medicators also contain trace elements often in a chelated form, but in most cases, few additional production responses are likely from these compounds. Chelated minerals are more available to the animal and may be metabolized differently. The usefulness of chelated vs inorganic minerals is dependent on several variables, though for most situations inorganic mineral sources are appropriate. Some work with chelated minerals shows improvements in calf health, conception rates and improved milk yields (Underwood and Suttle, 1999). The response may be dependent on basal mineral status of the animal, and interactions with other minerals present in the diet. These chelated compounds may cost 4-5 times that of inorganic minerals, making their use prohibitive (J Branum pers com).

11 Responses to water medication of grazing cattle

There is an extensive body of literature on the responses of grazing cattle to N and P supplements provided through traditional supplementation strategies (see reviews by McCosker and Winks 1990, Ternouth 1990, Winks 1990, Miller *et al* 1997). However there is a relative paucity of data on responses when these nutrients have been provided in the water, though anecdotal comments usually indicate positive responses. A further difficulty is that a majority of the available data has been derived from unreplicated observational studies, some of which have not been well designed. Several studies have been published comparing responses to traditional and water medication supplementation strategies. From a research perspective however, and in order to validate some of the claims for this technology, some additional objective research is warranted to quantify the magnitude of responses from water medication, and to more clearly define the critical factors influencing such responses.

Despite this caveat, a number of field observational studies have indicated positive responses to water based supplements in cattle under a range of environmental conditions. In a study in the spear grass region of north Queensland, McLennan *et al* (1991) reported that during the dry season in one of three years only, weaner heifers responded to urea and AS provided in drinking water, although a better response occurred when urea was fed as a fortified molasses mixture in open troughs. These differences were most likely due to higher urea intakes in the fortified molasses group, but also to the additional energy and minerals from the molasses source.

In another study, Bawden (1997, 1998), reported the results of a three year Producer Demonstration Site observation in the “desert” country of central Queensland where cow fertility, cow weights and weaning weights were compared in cattle offered supplements either as a dry lick or through a water medicator. During the dry season both urea and P intakes were higher in cattle on medicated water than on dry licks (urea, 22g *v* 15 g; P, 7.7g *v* 3.5g), with similar trends in intake during the wet season (urea, 18g *v* 8g; P, 11g *v* 8g). Pregnancy rates were 15% higher in breeders on medicated water than on dry licks (77% *v* 62%) although there were only small differences (15kg) in breeder weights, while average weaning weights were slightly but not significantly greater (190kg *v* 182kg) in weaners from cows on water medication. Proponents of water medication technology have sometimes used data of this sort to justify the technology, but this is not really a valid approach. The production differences detailed above cannot be attributed to the use of water medication technology *per se.* More likely they reflect differences in urea and P intakes from using these two strategies, which could be due in part to lower individual variation in nutrient intakes through water medication. It could be argued though that these reduced variations in intake in the water medicated group contributed enhanced production responses, thereby justifying the value of the technology. Moreover these reports highlight the fact that variations in intake of licks and blocks may, as mentioned earlier, lead to lower than hoped for production responses from that type of supplementation strategy.

At a Producer Demonstration Site in central Australia, lactating cows in Phase 1 of the study were either provided with supplements (N+P+S) through a water medicator or received no supplement (Hill, 2000, 2003). At the end of the first phase, supplemented cows were significantly heavier than control cows (446kg *v* 409kg), were in better body condition and had slightly higher pregnancy rates (53% *v* 42%). While average weaning weights were not different, total weaner weight was higher in the treatment group due to the higher fertility of this group.

In phase 2, where heifers were allocated to either water medication or control groups, though there were no differences in heifer weights, overall pregnancy rates were 21% higher in the water medication group, while in lactating heifers pregnancy rates were 30% higher (54% *v* 24%). Average weaning weights were similar, but again total weight weaned was higher in the water-medicated group. In both of these studies, cost/benefit analyses indicated positive responses were achieved, the central Australian study suggesting a benefit/cost ratio of about 9:1 or $213/lactating breeder/cow year.

In a study on the Mitchell grass associations of the Barkly Tablelands in the Northern Territory, Petty (unpublished) recorded liveweight gain advantages of 0.3kg/d in the early dry season and 0.1kg/d over the duration of the dry season, when weaners were provided with supplements through water medication, compared to unsupplemented controls.

In a survey of producers using water medication (Entwistle and Jephcott, unpublished), the authors received considerable anecdotal comments indicating positive responses in breeder fertility, growth and survival, and in weaner and growing stock growth rates and performance, where medication technology (NPN, S, P or combinations) were used. However, the authors were not aware of any additional analysable data measuring production responses to water medication, although this could exist. A collation of all available information and an economic analysis of outcomes could clarify the economic advantages and disadvantages, and help to define the optimal application of the technology.

12 Operational issues

A range of operational issues need to be considered in the application of this technology, a majority of which have been identified by Hirst (1996), Bawden (1997, 1998), Hill (2003), and Entwistle and Jephcott, (unpublished). In brief, these include:

- importance of determining water quality;
- consideration of approaches to improving water quality, including a range of available technologies;
- recognition of potential interactions between supplement components and water quality components;
- monitoring procedures for water quality and medicated water supplies, eg flow meters, pH meters, N test kits;
- selection of correct grades, types and combinations of supplements to minimise acceptability/intake problems and precipitation/sedimentation/organic growth problems;
- use of sealable light coloured polythene concentrate tanks to minimise evaporation, inhibit algal growth and reduce water temperature;
- selection of appropriate sized concentrate tanks that contain enough supplement concentrate solution to supply the average mob for a maximum of 7 to 10 days, ensuring fast turn-over of concentrate mix;
- importance of thorough and regular mixing of concentrate solution using effective mixing devices such as fire-fighter pumps;
- selection of appropriate types and sizes of medicators, ensuring adequate power supplies and consideration of built-in safety features;
- location and protection from weather and livestock of medicator units, power supplies and cabling;
- use of appropriate types of pipes and pipe fittings and installation techniques to minimise corrosion of pipelines and dispensing equipment;
- regular maintenance of units and filters, meters and other monitoring equipment and checking dispensing rates;

- thorough understanding of operations and calibration of units;
- accurate calculations for formulating concentrate mixes and calculation and calibration of volumes of nutrient solution required to be injected into the line to supply required levels of nutrients to the animal;
- regular and frequent monitoring of water quality , particularly pH;
- good data logging procedures for medicator adjustments and of water and supplement intakes, to ensure correct supplement levels are being provided;
- ensuring that where possible medicated water is the only water source in a paddock to minimise risks of urea toxicity;
- minimising chances of human error by appropriate staff training and supervision;
- monitoring production responses and doing cost benefit analyses.

13 The future of water medication technology

Improvements in technology and the ongoing development of safety units incorporated into medicators will enhance the safety and reliability of this technology. However, human issues such as a strong commitment to the technology, a recognition of the need for frequent monitoring and maintenance and an appreciation of the underlying electronic and mechanical components of these systems, means that the technology is not for all producers. The technology requires a high level of management and an understanding of the potential risks involved, in addition to an appreciation of how best benefits can be achieved across the herd.

Additional investigations are needed to further quantitate the production responses likely to be achieved under a range of different environmental and management systems. Some further work on the timing and levels of water medication supplementation likely to give economic returns could be fruitful, and a review and investigation of non-toxic NPN sources or, alternatively, soluble protein sources could enhance adoption rates through minimising potential toxicity problems. Many producers have also suggested investigations into the possible delivery of soluble energy sources through water medication.

This review and the widespread discussions of the authors with users of the technology (Entwistle and Jephcott, unpublished) have highlighted a major problem in some areas of water quality impacts on supplement delivery efficiency. Research leading to a better understanding of seasonal impacts on water quality, and of water chemistry as it relates to delivery of supplements would be a profitable area of future investment. Similarly, further development of simple and cheap field equipment and techniques for measuring important water quality parameters would benefit both current and potential users of water medication technology. In addition, there appears to be a need for an independent review, assessment and definition of the situations where commercially available methodologies and technologies for water quality modification and improvement could usefully be used. These technologies, some of which are quite expensive, are frequently being applied in a ‘band-aid’ manner, and their efficacy and efficiency is sometimes difficult to establish.

Finally, monitoring and maintenance of units will be an ongoing need. There is considerable interest amongst many users, particularly those on extensive properties, in the use of telemetry systems to assist with this monitoring. One commercially available unit now has capacity for integration with a radio telemetry system to enable monitoring and to activate alarm systems for parameters such as water flow, trough, concentrate and supply tank levels and, in the near future, sensing devices for urea concentrations. A large northern pastoral company is also undertaking research on telemetry systems for water supply and water medication installations. These developments are likely to lead to further commercial applications in the near future that will enhance safety and reliability of the technology, with potential time and labour savings.

However, some current and future water medicator users will feel more comfortable with less technologically sophisticated and simpler manual systems and will achieve outstanding results using this type of equipment. Some manufacturers and suppliers have indicated they will continue to cater for this class of user (M Peart pers comm).

14 Conclusions

This review of literature has attempted to highlight some of the known applications, advantages and limitations of water medication systems as applied to grazing beef cattle. However the use of this technology in intensive beef cattle feedlots and in land and sea transport situations has not been dealt with in any detail, since it is outside the scope of the review.

Water medication technology has wide potential application in those situations where control of watering points is possible, where water quality is suitable or can be appropriately modified and improved, and where management is adaptable and conscientious. Water medication has been mainly used to date to deliver a range of critically limiting macro and micro nutrients. However, provided suitable formulations are available, there are a range of other medicaments which could be delivered using water medication technology, including electrolytes and sugars to minimise stress and enhance meat quality, substances such as anti-tannin compounds to enhance digestion of fibrous or less digestible plant material, compounds to stimulate immune responses or control internal and external parasites, anti-bloat medicaments, and, where appropriate, organically based formulations to satisfy organically produced food standards.

Technological developments will lead to further improvements in the safety and reliability of these systems. However, while there are opportunities for more wide spread use of water medicators, for the reasons outlined in this review, their application in the Australian beef industry will not be universal. It should also be re-emphasised that adopters and users will be only those producers with higher level management skills and with an on-going commitment to the technology.

Finally, the complexity of water medication technology and its component parts means that a unifying principle for further development and application must be kept in mind at all times:

"The KIS(S) principle"

"KEEP IT SIMPLE (STUPID)" (with acknowledgements to Christopher Nott, "Alcoota" Station, Alice Springs)

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