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Probiotics - history, uses and future  
potential in sustainable agriculture

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**Probiotics – history, uses and future  
potential in sustainable agriculture**

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## **Executive Summary**

This research report is about probiotics, a natural means of promoting health, disease resistance and productivity in both plants and animals. The report draws on many information sources, from books, journals, trial information brochures and an interview with Dr Tim Jenkins, a prominent New Zealand microbiologist and formulator of some unique probiotic products.

The report gives an outline of the history and development of probiotics, looks in depth at both ruminant and plant/soil models for the use of probiotics, and reviews some result averages. From there is a look at the use of antibiotics in agriculture, and some of the inherent issues and problems for the future. The report then looks to assess the role of probiotics in sustainable agriculture and looks at potential future directions for probiotic research and applications.

In all the report gives an overview of the development, the how, when and why of use, some quantification of measured results, and an in-depth look at the potential for probiotics to used as a natural alternative to antibiotics.

## **Introduction**

This report aims to give the researcher a more complete understanding of the background, place and potential of probiotics in current day and future agricultural production systems. This is an exciting opportunity to learn more about this expanding area.

Probiotics have, as I see it, an important role in farming systems, with good scope to improve efficiency with which inputs are utilised by both animals and crops, in a sustainable manner.

Input use efficiency is a fundamental cornerstone to the long term sustainability of agricultural production systems, and it is these type of efficiency gains that help build on the solid foundations (in most area's) of current systems for the future.

Resource depletion and the rising demands of population increase provide an important impetus for any methods which can maximise the efficiency of input use for sustainable production systems in the future.

Probiotics have been shown to have the potential to achieve the aims of increasing input use efficiency of both animals and crops, and this report aims to quantify this in real terms, in the present and for the future.

## **Probiotics – a definition**

The basic concept of a probiotic is an organism or substance given to an animal, naturally produced by a probiotic (beneficial) organism which aids the health or productivity of the target animal. The concept of a probiotic can also be applied to plant and soil effects, whereby the probiotic enhances crop health or productivity and/or stimulates soil microbiota (probiotics for soil / plant use are described as 'biostimulants').

The term 'probiotic' was first used in 1965 by Lilley and Stillwell, but not in an animal supplementation context. This was first done in 1974 by Parker [2] in the context of describing organisms isolated from faecal suspensions, free from pathogenic organisms, used to restore or supplement the microbial fauna of the gastro-intestinal tract in animals. At this time Parker defined probiotics as:

*'Organisms and substances which contribute to intestinal microbial balance'.*

This definition was modified in 1989 by Roy Fuller [1] (an eminent probiotic researcher) to:

*'A live microbial feed supplement which beneficially affects the host animal by improving its intestinal microbial balance'.*

This definition is again a little outdated in light of research into the effective modes of action of probiotic formulations in an animal context [1] [3]. Modern research has identified that it is often active probiotic components from probiotic bacteria (which include cell wall fragments, short chain proteins, and antibacterial proteins), which activate the positive effects evident from testing, and not the living probiotic cells. This is backed up by research showing equivalent efficacy of live versus killed probiotic formulations on animal productivity [3].

In light of these facts it is perhaps advisable that the definition of what a probiotic is could be revised backwards (to be less limiting) to the first definition by Lilley and Stillwell, researchers who in 1965 used the term *probiotic* to describe 'substances secreted by one micro-organism which stimulate the growth of another'. This definition implies that a stimulatory probiotic effect is not the direct result of a particular micro-organism, but of what that micro-organism naturally produces, which I believe is a more relevant description for a modern probiotic.

## **Development history**

The term 'probiotic' in relation to feed supplements is a relatively recent occurrence in contrast to the earliest recorded references of the intentional use of fermented foods (*ie*; fermented by microbes).

The earliest of these references was to the inoculation of milk to induce fermentation, recorded in wall paintings by the Sumarians as early as 2500 B.C. The use of fermented milks as food, were recorded in the Old Testament (Genesis 18:8) [1].

The relationship between the consumption of 'fermented milks' (before the term 'yoghurt' was in use) and long life was first established by Elie Metchnikoff in the early 1900's. Metchnikoff's book '*Essais Optimistes*'

(optimistic studies) published in 1907 establishes Metchnikoff's work as the birth of modern probiotics [1].

Interest and research in microbes in food and gastrointestinal health halted during both World War's 1 & 2, but was revived post WW2 with the advent of antibiotics (and the related negative effects on intestinal microflora), and the ready availability of germ-free animals for studies.

From the mid 1940's to the mid 1960's, the view of gut microflora altered from having a potentially adverse effect on the animal, to having an important contribution to the nutrition of the host and being involved in protection against disease.

This shift in thinking directed research into the area's concerned with evaluating productivity advantages of inoculating animals (both monogastrics and ruminants) with live microbial suspensions.

Initial focused research was based around isolated rumen specific bacteria which induced a positive overall effect for the inoculated animal.

From the mid 1960's through till the mid 1990's, there were many thousands of experiments and trials performed with probiotic formulations, and these gave a good foundation for the most effective commonly used probiotic organisms now in use. From the mid 1990's through until today, probiotic research has progressed a lot further, particularly in identifying modes of action and the molecular basis of probiotic components.

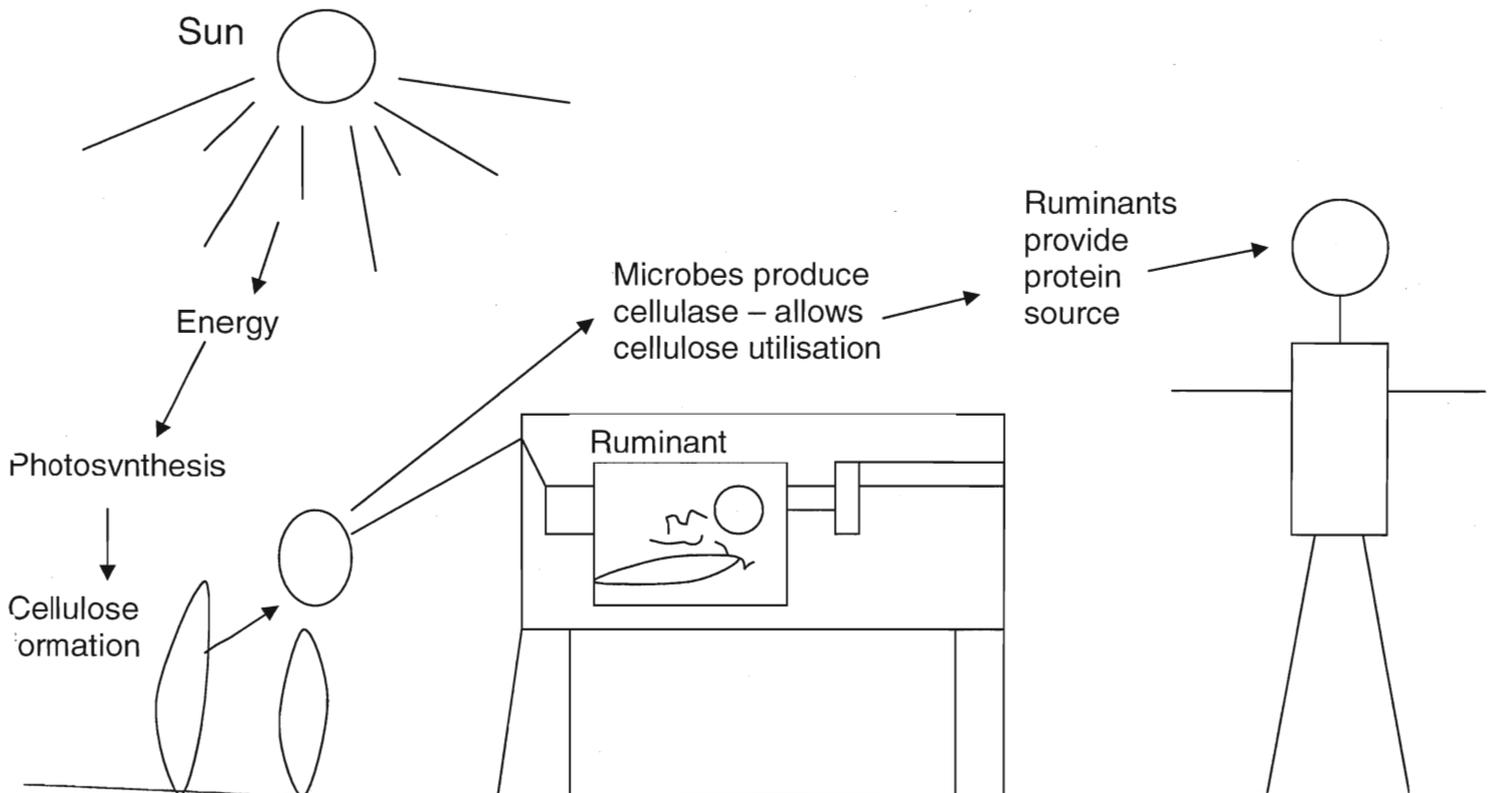
The highly publicised and increasingly concerning advent of continued resistance to antibiotics by bacteria has also played an important role in the recent development of probiotics, as well as creating a heightened awareness of natural alternatives to antibiotics, in both medicine, and food production systems.

A lot of research for ruminants has been based around the intensive feedlot systems of North America and Europe, but there has been limited research based around pastoral farming systems and the use of probiotics.

## The Ruminant Model

The basis of life on earth is the presence of the sun. The sun radiates energy produced by nuclear fission and energy is a prerequisite for life. The main way in which this energy is stored is through photosynthesis, performed by plants. The main proportion of plant biomass produced by photosynthesis is the structural carbohydrate cellulose, which gives plants rigid cell walls, and thus their physical structure. Carbohydrates are chains of units of simple sugars, which require specific enzymes to break them down into their component sugars for energy use. The most abundant carbohydrate, and thus energy source, on the earth is cellulose, and the specific enzymes for its breakdown, the 'cellulases' are unfortunately not synthesised by any multicellular organisms (including humans and ruminants). Fortunately, certain herbivores (mostly ruminants) have evolved a system whereby they can have cellulase enzymes produced for them in the specially adapted fermentation forestomach, the rumen. This in turn allows these herbivores to utilise one of the largest, sustainable energy sources on the earth (Cellulose in plant biomass), and convert it into the protein that humans require for nutrition (and clothing in the case of animal produced fibre).

A very simplified model is shown below:



This simplified model depicts one of the most important material flows in the biosphere, in which humans are dependant on the association between ruminants and rumen microbes which ultimately provides for part of our sustenance. The fact that we are so dependant on this association forms the basis of means to sustainably improve this process (through the use of probiotics) for the benefit of an expanding global population.

So how do probiotics achieve this?

Research in the past fifteen years has greatly helped our understanding of the mechanisms (or 'mode's of action') by which probiotics for animals work in the intestinal environment (concentrating on ruminants).

The key modes of action identified are:

- The presence or production of organic acids – these naturally stimulate beneficial rumen microbes.
- The supply of specialised complex sugars such a mannan – oligosaccharides which provide a substrate which aids the growth of cellulolytic (cellulase producing) bacteria.
- Stimulation of gut wall immunity – this occurs by two mechanisms; cell wall fragments from probiotic bacteria and yeast fungi stimulate the production of IGA antibodies (which are the first line of defence in the gastro-intestinal tract), and live probiotic microbes can colonise and adhere to the villi of the gut wall and exclude pathogenic bacteria from gaining a foothold. This is a very important mode of action as up to 80% of the total immunoglobulin producing cells of the body (of mammals) are localised in the gastro-intestinal tract [9].
- The production of microbial growth promoting substances – these aid the multiplication of beneficial rumen microbes (not just bacteria – also fungi and protozoa).
- The production of natural proteins called 'bacteriocins' which inhibit, and can even kill competing pathogenic bacteria [9].
- Oxygen scavenging – research has shown the ability of the probiotic yeast *Saccharomyces cerevisiae* to reduce oxygen levels in rumen fluid (which are around 0.5 to 1.0%) to aid the growth of beneficial cellulose digesting anaerobic bacteria [5].
- Increasing the levels of cellulolytic bacteria (shown as an effect of the yeast fungi *Aspergillus oryzae* and *Saccharomyces cerevisiae* [5].
- Stimulation of lactic acid fermenting bacteria – this helps to maintain rumen conditions at an optimal pH (5.8-6.5), which are the best conditions for the cellulose digesters.

In all, multiple modes of action have been identified by which probiotics effect their actions. Of course this information is of little use without some quantification of what this achieves. A summary of averages of some key production parameters measured is detailed below:

Type of probiotic	Parameter	Livestock	Level of response
Yeast – <i>Saccharomyces cerevisiae</i> [1]	Milk production	Dairy cattle	0 - 8%
Yeast – <i>Aspergillus oryzae</i> [1]	Milk production	Dairy cattle	4.3%
Yeast – <i>Saccharomyces cerevisiae</i> [8]	Methane production	Dairy cattle	0-10%
Yeast – <i>Aspergillus oryzae</i> [8]	Methane production	Dairy cattle	0-50%
<i>Lactobacillus acidophilus</i> [12]	Weight gain	Calves	17%
Lactate utilising bacteria [6] (multiple strains)	Feed utilisation & Daily weight gain	Feedlot beef cattle	2.5 – 10.5%%
Multi strain probiotic with fungal and bacterial extracts[7]	Liveweight gain	Weaned lambs	10-21%

These averages show some significant responses in varying parameters to the use of probiotics in animals. Unfortunately, in several studies the responses to probiotics have been limited and variable. This reflects the highly variable environment in which probiotics have to work, and now that modes of action of particular probiotics and their components are becoming better understood, it is thought that in the future more consistent results will be more easily achievable. Other positive effects of probiotics are sometimes not taken into account, as in the example cited by Seymour [10], which showed a reduced requirement for antibiotics in probiotic treated calves to maintain good health.

## The Plant Model

The effects of biostimulants (probiotics for plants and soil) on crop yields and health and the biological diversity of soils has been much less studied than probiotic responses in animals, however there is much scope to change this in the future, as research funding becomes directed more towards sustainability. Plant and soil biostimulants are based around a lot of the same probiotic microbes as used in ruminant probiotics. Why is this? – there are a lot of similarities in some aspects of soil and rumen microbiology. It is important to understand that most of a ruminant's microflora is obtained directly from plant material ingested. Through this mechanism plant and soil microbes have been an integral part of the evolution of the ruminant, and the microbes which evolved to break down plant material on or in the soil, also evolved to break down this material in the rumen of ruminant animals.

Biostimulants work via a variety of mechanisms, both on and within plants and within the soil ecosystem:

*Within Plant* – ( these compounds absorbed via stomatal uptake)

- The eliciting of plant defence responses – cell wall fragments and organic acids can produce these responses which enhance plant immunity (in a similar manner as cell wall fragments stimulate immunity in ruminants).
- Natural growth promoting hormones (such as Auxins and Gibberellins) produced by probiotic microbes stimulate plant growth.

*On plant* – Viable live microbes

- Repopulation – viable microbes can repopulate leaf surfaces, reducing the potential for pathogenic (disease causing) microbes to infect plants.

*Within Soils* - both viable microbes and non-viable components

- Stimulation of soil microbes directly enhances nutrient cycling and turnover and aids the utilisation and uptake of nutrients in the rhizosphere of plants.

The results of biostimulants trials are limited, and are generally confined to in house commercial trials, however in a New Zealand context, a biostimulant product for viticulture has been trialled by HortResearch over 3 seasons. The results for this biostimulant ('Foliactive') have been

particularly promising, with reductions in infection by bacterial and fungal pathogens being similar to levels achieved by chemical fungicides. These results are considered to be achieved by the combined actions of the eliciting of plant defences, as well as repopulation of leaf surfaces.

Some in-house field - trialwork with another Donaghys product ('PastureAid') has shown evidence of increased nutrient utilisation, with the effective response to the application of urea being increased by 7% when combined with the application of the product. Of greater interest was the response to the product applied alone at a higher rate (6l/ha) which achieved a 34% increase in DM production compared with a 27% DM increase from a urea application of 32kg/ha.

Overall biostimulants have been shown to increase resistance to pest and disease, increase plant quality (higher DM percentage), and improve productivity (higher DM overall). These results are admirable, but more focused research is required in the future if agriculture is to realise the potential of biostimulants to aid sustainability. There are several reasons other than straight out productivity increases why biostimulants are an important potential tool for the future.

The major reasons are related to efficiency of fertiliser use. Agriculture faces a future where some of the key fertiliser inputs – especially phosphorous and nitrogen, will be significantly more expensive. Both because of resource depletion, nitrogen because of the increasing price of oil affects the cheapest N form – urea, and phosphorous because there are definitely finite reserves available (it has been predicted that the worlds reserves will be exhausted in 100-200 years). These two factors alone create an impetus to increase the efficiency of fertiliser use, in which biostimulants could play an important role.

There are several situations where excessive fertiliser usage can reduce both the efficiency of fertiliser use and negatively impact on soil microbial activity. For example, excessive nitrogen and sulphur fertiliser applications result in leaching of these elements which take calcium with them, which impacts negatively on soil microbial activity. Excessive sulphur levels can also be detrimental to earthworm activity, which is important for nutrient recycling in the soil.

Excessive phosphorous levels can also reduce available calcium, as well as reducing the levels of vesicular arbuscular mycorrhizae (VAM). VAM infect plant roots (eg. Clover) and in return for getting carbohydrates from plants, VAM effectively increase the plants root zone and give plants greater phosphorous, water and trace element uptake efficiency.

### **Current uses and adoption**

The uptake and usage of probiotics and biostimulants in New Zealand has been relatively limited in comparison to some northern hemisphere regions. Probiotic knowledge and use has been more extensive in both North America and Europe, mainly due to the predominance of more intensive feedlot production systems. These systems have in recent history relied on the use of antibiotic growth promoters, and have played an important role in the impetus for the development, and provided for the trialling of natural alternatives, including probiotics.

In a New Zealand context, while the situation has been a little less dynamic, the awareness and usage of probiotics and biostimulants is increasing [4]. One has only to look at references in agricultural and wider literature for the now common references to probiotics, compared with 10 years ago, when references were sparse to absent. For example, in 1998, there were only three 'probiotic' products available which contrasts with the fifteen currently available products.

Some of the issues relating to the slow uptake and usage of probiotics in New Zealand have been identified [4].

These are:

- Perceptions – that probiotics are new and unproven;

This has been countered by trialwork in New Zealand which has shown benefits in a number of varying situations.

- The knowledge of modes of action of probiotics has been limited (failing to give the potential user confidence);

The knowledge of modes of action has advanced greatly in recent years, and this has increased confidence.

- A criticism of probiotics has been that they are a solution to fix problems that good management practices should avoid;

It is now well known that even the best management practices do not necessarily result in optimal rumen conditions. This criticism also fails to take account of the now well documented effects of probiotics on immunity.

- A further criticism has been the perceived lack of response, when no objective measurements are available (such as Faecal egg counts to assess anthelmintic efficacy), or made;

Often the effects of probiotics can be variable, but in the majority of trials they show some form of measurable response. In the future, there may be simpler objective measurements available which can indicate rumen efficiency (eg. pH sensors).

- Economic considerations – because probiotics are a secondary, or discretionary item, they are the first inputs to be chopped if the profitability of farming declines, which is an ever present reality for the New Zealand farmer, producing relatively low value commodities in an exposed marketplace where currency fluctuations can greatly alter our profitability within short timespans.

This, combined with the other issues will continue to hinder the uptake and usage of probiotics in New Zealand, although, as time goes by some of these issues are becoming of less relevance.

## Probiotics vs Antibiotics

Probiotic formulations for animal feeds first became of interest as alternatives to antibiotics as growth promoters in the 1960's.

Administration of antibiotics to animals has been used in dealing with pathogenic bacteria since the 1940's [8]. This was still fairly much in the 'invincible antibiotics' era, however, even this early on, scientists had genuine concerns about the development of antibiotic resistance (in 1969 the Swann committee limited the use of antibiotics as growth promoters to only those antibiotics not being used in human medicine [1]). In fact, the first account of a bacterial strain that was resistant to penicillin was published at about the same time penicillin was introduced into medical use, it just took about three decades for science to catch up, and understand how this resistance worked [9].

Antibiotics have been, and are still, widely used in intensive animal production systems to promote liveweight gains and productivity. Early antibiotics used including penicillin and tetracycline stimulated the resistance of potential human pathogenic strains of E.coli, which caused their eventual banning for use as growth promotants in some countries. There is growing concern that the use of antibiotics as growth promoters may result in the development of resistant populations of pathogenic bacteria, and in turn, influence the therapeutic use of antibiotics [8], as shall be seen, this is already occurring.

Some examples of antibiotics used as growth promoters are Tylosin, Virginiamycin, Fluoroquinolone, Salinomycin, Avoparcin and Tetracycline. Tetracycline is also used in horticulture for the control of fireblight. There is widespread bacterial resistance to the tetracyclines, however this antibiotic still has important uses against some serious diseases. Tetracycline is effective against Anthrax and Lyme disease.

Tylosin is a macrolide type antibiotic and is used in pig farming to prevent bacterial respiratory diseases, as well as a growth promoter. Tylosin is in the same group of antibiotics as erythromycin, and is similar enough to cross-select for resistance to this important newer type of safe antibiotic. Tylosin can also select for resistance to two other important antibiotic groups, Lincosamides and Streptogramins.

The Streptogramins were hailed as a new antibiotic type, which were not affected by resistance to Vancomycin (the previous unbeatable antibiotic). However the use of Tylosin and Virginiamycin in farming has been implicated in creating resistance to this antibiotic type via cross selection for resistance mechanisms by similar groups.

Fluoroquinolone use (as 'enrofloxacin') in poultry farming has led to the development of resistant *Salmomella* bacteria. This in itself is concerning, however more concerning is the fact that the fluoroquinolones are one of the last antibiotic types which are still effective against TB, a devastating bacterial lung infection, which is staging a massive comeback, which has originated in developed countries who became complacent and sloppy in the prescribing and followup of long course antibiotic therapy [8]. If agricultural use of Fluoroquinolone leads to resistance in TB, we are in serious trouble.

The list of agricultural antibiotics that that are considered safe in the sense that they do not cross-select for resistance that could impair important human use antibiotics continues to shrink [8].

Another common type of antibiotics used in feed supplements or directly fed to animals are ionophore antibiotics. This involves the direct introduction of antibiotics into the rumen, one of the most . The main types of ionophore antibiotics are sodium monensin (the active ingredient in 'Rumensin'), Lasolacid acid, and Salinomycin

Another recently discovered fact, which has alarming potential, is that the environmental stability of some antibiotics is far more than previously thought [9]. German scientists measuring chemicals released from a sewage treatment plant found high levels of an initially unidentifiable compound, which when finally identified turned out to be the antibiotic Fluoroquinolone. This blew away the common misconception that antibiotics were no longer active beyond their initial target. Scientists have had to adjust to the fact that antibiotics are flowing from sewage treatment plants and farm manure storage pits directly into human water supply's in some area's. Incidentally some other compounds being found at high levels are heart medications and hormones.

The main problem with antibiotics is their broad spectrum killing of a range of microbes, both good and bad. Probiotics contrast this by their action to selectively promote the growth of beneficial microbes, which naturally control and out-compete the harmful kind.

Probiotics are a far safer concept for the prevention of disease, as they work primarily to strengthen the body's natural defence mechanisms against disease, and also work via multiple modes of action, contrasting with antibiotics which generally have a single mechanism which can be easily thwarted by the development of resistance. Also – part of the problem with antibiotics is that they are highly refined and concentrated, which leads to problems with residues in meat, milk and other food products consumed by humans.

Probiotics are non – residual.

While probiotics have been shown to reduce the incidence and severity of disease challenges, they have not been shown capable of effecting the same levels of elimination of disease as can occur with the right antibiotics in the right situation. However, it is my view that the common most common scenario's where antibiotics are required and given to domestic livestock, and which create a need – highly intensive feedlot conditions, are a part of agriculture that needs to be changed for the future. It is indeed, the close confinement and housing of vast numbers of the same type of animal that causes and aids the development of disease (for a human example look at prisons and the emerging TB problems).

The growing of livestock in more natural, non-confined conditions, is a far better option, and reduces the need for products like antibiotics and their associated problems. This is where future probiotic products can play an important role in maintaining the health of livestock.

Probiotics embody the concept of biological diversity in their action, this is the direct opposite of antibiotics, which are highly concentrated compounds with a single mechanism for action. This diversity of action means it is virtually impossible for microbial resistance to occur to probiotics, and even specific probiotic compounds, such as bacteriocins, natural proteins which unlike antibiotics, specifically target a species (rather than a large group) of bacteria, eliciting multiple killing mechanisms. Bacteriocins could well be the future replacements for antibiotics, and they have the bonus of having virtually no side effects, or residue issues.

## **The role of probiotics in sustainable agriculture**

I believe there is an important role for both plant and animal probiotics in the future for sustainable agriculture.

The potential of plant/soil probiotics (biostimulants) in aiding the sustainability of intensive cropping systems is vast. Systems where monocultures are used extensively put a lot of disease pressure on those plants, and the overuse of chemical and synthetic inputs can greatly reduce the natural biological diversity important for both the natural plant defences and the efficient utilisation and cycling of nutrients. Biostimulants have shown the potential to aid these important factors, factors which are going to be increasingly more important as the cost of inputs rises, and pressure on resources increases.

The potential of animal probiotics to aid sustainability has been shown to some extent. For example, the use of probiotics to increase feed use efficiency and reduce methane production are both very important measures which need to occur in the future as environmental (both socially and physically) pressure forces agriculture to improve sustainability and efficiency of production. The use of direct fed microbials (live probiotics) has been shown to have a number of important effects: reduction in scouring of calves, increased milk yield in dairy cows, decreased death rates in newly weaned calves arriving at feedlots, increased daily weight gains and carcass weights in feedlot cattle, and improvements in immunity [4].

Overall these results in animals and the results for biostimulants show a definite place for probiotics to aid agricultural sustainability.

## Future directions

Research on microbial feed additives is often frustrating, because responses are often small and can be quite variable. However, as progress is made in defining the modes of action for various probiotic microbial components, predicting the best specific situations or feeding conditions where responses are consistent should be possible. The past 10 years of probiotic research, combined with the technology improvements in molecular science and genetics has allowed a far better picture and understanding of the ways specific microbes and their components elicit particular responses.

Some of the key areas of future potential are:

- The use of slow release probiotics which out-compete and minimise the effects of methane producing bacteria.
- The use of targeted probiotic components which enhance feed conversion of particular feed types.
- The use of recombinant techniques (genetic modification) to improve the action or function of specific rumen microbes.
- The identification of specific probiotic bacteria and fungi for specific crop or soil types, to better enhance biostimulant effects
- The identification, isolation and eventual production of specific probiotic components (eg, bacteriocins) which are safer and far more specific than current use antibiotics. (This would seem to go against the 'diversity of action is best' theory, but bacteriocins kill by a variety of mechanisms – thus increasing diversity of action compared with antibiotics).

There is potential for probiotic organisms and components to produce more natural alternatives to some synthetic chemical compounds (eg. Fungicides), as well as antibiotics, however a lot of investment needs to be made in developing such products, which is currently not occurring.

## Summary

Probiotics are formulations of proven beneficial microbes, or the products of, which are used to aid the health and productivity of plants and animals. Probiotics have been in use, in a sense since 4500 years ago, but their serious modern development began in the last century, during which time they have progressed from fermented milks, through faecal suspensions for dosing, to the highly specific, scientifically proven formulations in use today. It is advised by some scientists that the study of probiotics is still really in its infancy, which gives good confidence for what can be achieved in the future. The definition of a probiotic has changed in the past, and is likely to change again in the future as more is learnt. The majority of probiotic research for animals has been based around concentrate feed utilising feedlot production systems, in both monogastric animals (chiefly chickens & pigs) and ruminants. This has meant a lack of studies using animals in more natural pastoral based grazing systems, as in New Zealand. This is being countered with more field trials now being performed in New Zealand, which should help to increase the uptake and usage of probiotics in our farming systems. There are also probiotic products for plants and soils, which show good potential for aiding the sustainability of future farming systems, which need to be far more efficient in terms of minimising inputs and utilising available nutrients.

The ruminant and its associated rumen microbes have been shown to be at the centre of one of the most important cycles by which our sustenance is provided, and it is this association between microbes and the ruminant which show potential promise for increasing the efficiency and sustainability of the production of meat in the future.

The levels of response to Probiotics are economically viable (cost:return) and while variable, there is good confidence that more consistent responses can be had in the future.

Probiotics may play a vital role in the future as providing natural alternatives to antibiotics, which are quick to encounter resistance in both human and animals, which is hastened by the use of antibiotics as growth promoters. Probiotics could be at the centre of new sustainable, and environmentally friendly agricultural production systems. For this to occur, more investment into research is vital.

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