Donald Oration 2006

Decision Support for manageable and unmanageable limitations to crop production

J.W. Bowden

Western Australia Department of Agriculture, Northam, Western Australia, 6401

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Introduction

In recognising the calibre of the Donald Medallists, and knowing the list of previous recipients, I am honoured to be placed among them and intimidated by the implications of being recognised in this way. I would like to thank whoever it was who proposed me, and the past, present and future presidents of the Agronomy Society who selected me for this honour.

Unfortunately, I never met Colin Donald and so know him only by his reputation (Fischer 2004), his students (John Hamblin, Brian Trenbath, Walter Stern, Don Puckridge and other major contributors and thinkers) and his ideas – particularly on pasture ecology (Donald 1946), pastures and competition (Donald 1963) and crop ideotypes and harvest index (Donald and Hamblin 1976). His breadth of interests, depth of understanding and most of all, his quantitative approach to research, make me wish I could have had one-to-one discussions with him on topics of mutual interest.

One of his insights on crop density and rooting depth struck me when I first got involved in N leaching work in the early '80s and again with more recent row-spacing research where we crowd plants together in wide rows at the same seeding rate as in narrow rows. My proposition was that crowding the plants such that they interacted earlier in their quest for soil resources, would find them allocating root carbon to more rapid exploration of the inter-row and also to depth. Donald however found that as per-plant performance decreased with increasing density, root depth decreased, resulting in a reduction in the total soil resources of mineral N and water available to the crop. He used this idea to explain a result (counterintuitive and obvious after it is pointed out), which had nitrogen (N) uptake per unit area dropping away at extreme densities. Under what conditions competition pushes roots deeper and then per-plant resource capture constrains rooting depth would make an interesting model. My feeling in reading his ideas, is that Colin Donald would have been a very astute modeller of crop and pasture performance if he had lived his working life in the computer age.

Much of my career has been to summarise mountains of data into a form which makes them available for direct use by farmers or for extension – the D bit of R, D&E. While I have gathered a lot of my own information, my main role has been to summarise information gathered by others – some published, most not – and turn it into what are now known as decision support systems (DSSs). The objective has been to take what are largely site, season and management-specific research results and make them transferable to, or useful for, the circumstances of individual growers My (mainly unpublished) efforts have been in the area of plant nutrition, but the obvious interactions of nutrition with soils, seasons, management and farming systems, means that I have dabbled in most areas of agronomy covered by this conference albeit, often, at a facile level.

In this paper I will take the opportunity to ride a few hobbyhorses and air a few ideas arising from my attempts to get a little bit quantitative about the outputs of biological research while at the same time trying to help grower decision makers.

Modelling – statistical vs process based

Any data summarising and any prediction, requires some sort of agricultural arithmetic or modelling. Biometrics ruled the roost when I was a pup (as it still does today) and so my first efforts in the modelling of multivariate data sets and curve fitting, was with correlation and statistical (linear) regression models. To fit curves, you had to either transform your data and/or add in various powers of your variables or you had to linearise your equations. Long and troubled hours with the vagaries and contradictions of models chosen by objective polynomial fitting together with long arguments on the need for orthogonal polynomials (now principal component analysis), led me to the conclusion that there must be a better way of developing predictive models. After three years with the WA Dept of Agriculture (WADA), trying to calibrate a soil test for phosphorus on wheat, the statistics frustrated me so much that I transferred to UWA for a PhD in soil chemistry. Soil chemists in those days were modellers but had little or no idea of how to apply statistics to their work.

On returning to WADA, I took on a project to further develop our recommendation system for P on crops and pastures. In this endeavour, I was led into the pathways of statistical unrighteousness by one David Bennett. We had to produce something which was simple, transparent and comprehensive. Our initial objective was to come up with a P-fertiliser recommendation system which could be applied to any situation defined by simple inputs from growers. The result was a DSS called DECIDE which I prefer to generalise as "the response-curve prediction" method of making fertiliser recommendations. DECIDE took a simple Mitscherlich response curve [Y = A*(1-B*exp(-C*Pfert))] which was defined by the imaginatively named parameters A, B and C and to which we could ascribe some readily understandable descriptors. Thus, A was the scaling factor for yield potential, which could vary with any known non-P factor (e.g., species, time of sowing, soil type, season, seeding rate etc). The job of the user was to give that parameter a value to scale the response curve so that economic analyses could be applied to determine the optimum rate. Similarly, B (the responsiveness which depended on soil-P status as well as species, season, soil, etc.) and C (the scaled curvature or efficiency parameter that depended on P-source, timing, placement, species etc) could be prescribed by the user with a bit of help from the research community.

My point here is that in this simple agricultural arithmetic approach to modelling P responses, we have a robust structure which allows for extrapolation to other crops, other systems, other nutrients, other seasons, etc without the massive resources required to handle those other situations if we were to adopt the statistical regression approach. We use regression to develop predictions of some of the parameters and we certainly use statistical curve-fitting to derive the A, B and C parameters, but we do not have to repeat a large set of standard trials again if we want to change our recommendations for a new or changed system (Bowden,1989).

As agronomists, we can do better than just re-describe data sets using multivariate analyses. We can bring our process-level information together with the statistical approach to develop more sensible prediction systems that are transferable to other situations

Model first, experiment second

When you live long enough you see a lot of recurring events and the re-discovery of many ancient wheels. For example, when a "new" problem or species/cultivar becomes a candidate for our agricultural systems, there is a temptation to rush in and throw a range of agronomic management practices at it so that you can rapidly have a package for use by growers. Unfortunately, because agronomic management interacts markedly with site and season, there will never be enough trials done to handle all the situations which need to be addressed by the "new package".

A far better and less resource-expensive approach is to critically examine what is known about the principles which apply for existing packages or recommendation systems for similar crops or problems. You then design experiments or trials around the factors which you think are most likely to prove your existing system will make wrong recommendations for the "new" variety or problem.

A simple example is the introduction of durum wheats into our wheat-growing systems. We do not need to run hosts of seeding rate, sowing time and nitrogen-rate trials and/or factorials over a full range of soils and seasons – you can never do enough. We simply need to examine what we know from the wealth of work on other wheats (or even restricted to hard wheats if we have enough information), to come up with a starting package. We then use intuition (or refer to someone else) to work out which major characteristics of durum wheat will require a difference in the package. Does the durum have different phenology? Partitioning to roots? Tillering? Harvest Index? etc? If so, how would this cause differences in response to management/agronomic factors? Rather than rush out and do an inadequate number of trials to try to define durum's adaptability, we should look at generic adaptability models and see where they have degrees of freedom for reading the specific physiological qualities which distinguish durums from other wheats.

Another example is the claim that we have a new crop or pasture legume species which will revolutionise the N economy of a rotation. Do not just quote the larger N input from a few species trials to back the claim. Read the N input in the context of the N availability and budgeting models which take account of the big things, like amount of N grown and rates of mineralisation of that material. What specifically does the new species do to invalidate the existing models or do we simply have to adjust some of the parameters because it grows more or less N under different conditions?

So, model first (the literature review) and find the critical gaps for your research. If there are none then use the existing system. Don't try to invent new wheels. If you have something new which cannot be easily accommodated by the existing system, then get that system changed such that it handles all the existing species/problems but also can now handle yours.

Levels of modelling for DSSs

All the best literature (and common sense) says that you should understand your system at a finer level of resolution than that at which you wish to deliver. Passioura, (1979) emphasises the need to relate our understanding at the higher and lower levels of the organisational scale. For example, if you want to deliver N fertiliser advice, then understand the processes which get N into the plant – do not just summarise N fertiliser trials and deliver the average results. If you just do the latter, you will be found out by circumstances not represented by your data set. This is a bit like the statistical rule that you should never extrapolate beyond your data set when you use regression equations. This begs the question of what level of modelling is appropriate for any specified task? The choice of level happens to be one of the main problems we "D" people have to face. It is tempting to try to force the level you are comfortable with onto every problem which is thrown your way.

In the early '80s, I saw massive resources put into developing a daily time-step simulation model to determine if it was worth opening up a section of new land in WA between Lake King and Salmon Gums. All that was really required was an annual time-step estimate of yields (probably at the level of prediction provided by French and Schultz (1984), though taking account of soil type when looking at a new region might be a good idea!) such that the economists could do some risk analyses.

I tend to opt for several levels of presentation of material to support decision making because my experience with diverse target audiences who have different educational backgrounds and different capabilities and preferences for handling material.

For our N DSSs we estimate available soil N supplies using tables as simple as only 12 numbers for the whole of Western Australia (yearly time step with 4 rotations by 3 rainfall regions) and hard-wired N-availabilities. We also have simple dynamic models (weekly time-step with a water balance that drives mineralisation of organic N and leaching of nitrate N reflecting soil type, rooting depth and rainfall) as well as access to simulation models such as APSIM (that work on daily time-steps, and integrate N-supply characteristics with crop growth, development and N-demand). Delivery of N fertiliser advice from these levels of modelling can be as simple as the commonly used and understood "N fertiliser required = N demand – N supply" through predicted yield, quality and dollar response curves of the intermediate models, to the less understood, detailed, cumulative frequency distributions (CFDs) of yield, protein and dollars from simulation models such as the APSIM-based Yield Prophet (Hunt et al. 2006). If we are to help a whole spectrum of users, we need to deliver at a whole set of levels.

Options: One size does NOT fit all

Despite their obvious utility and extendibility, I have always hated "packages" (often "best management") and recipe-book recommendation systems such as we can readily deliver by computer. They target "economically rational" people on some "representative" or "average" farm and they invariably deny the individuality of people and situations.

There are usually plenty of options but rarely only one solution to any farming system's problem whether it is how much fertiliser to use, how to manage stubbles or even how to stop recharge of saline water tables.

A few years ago, I attended a "deep sands workshop" at Esperance. On day one, the speakers – who included several farmers, hopped on a bus to look at some of the case studies of how different growers were trying to reduce recharge of the water table. One farm had belts of Tasmanian blue gums which were demonstrably transpiring a lot of water – and the timber was almost at a harvestable level of maturity. Another grower had planted the sands to rows of *Tagasaste* which were being grazed by young beef cattle – because his brother and father on a dairy farm 600 km to the west were turning off the weaner cattle. Another grower did not like cattle or forests and had planted lucerne which she grazed with sheep. Yet another grower was trying cropping solutions to use as much of the excess water as possible. For any problem, there are many different solutions which suit different people.

When commercial soil testing first got going in WA in 1971, the WADA did a survey of users on what they thought of the service and how it affected their fertiliser usage. In round figures, 30% said it recommended too much fertiliser P, 30 % said it recommended too little and the remaining 40% said it recommended what they were going to do anyway. A 100% failure for the soil-testing package.

With the DECIDE method, we tried to develop a P-recommendation system that took account of individual growers' risk preferences. We had a magic parameter "R" which they could scale up or down according to their feelings about spending certain fertiliser dollars for a very uncertain yield dollar. The growers from whom we got feedback, would use our individually tailored "final recommendation" as a starting point for their final determination of how much P they would apply after they considered other, more important factors which impinged on how they would spend limited dollars. Could they get a better return from putting fertiliser dollars into sheep or renovating the kitchen or even sending their offspring to boarding school?

I recognised this problem in 1978 when I was asked for fertiliser advice by two neighbours who were in identical biophysical environments. Our recommendation system took account of the demand (as represented by yield potential) for nutrients and so seasonal variability came into the discussion. One farmer said he fertilised every year for the good seasons because the additional returns in those seasons, well and truly paid for any over-fertilising in the poor and average seasons. His neighbour pushed the line that he fertilised for the poor years because that was when cash flow was worst and he had to survive for the next year – and anyway, even though grossly under fertilising when a good season came, he still made a lot more dollars than normal in that year and was happy for that. To my mind, both farmers were correct.

This experience convinced me that we should not be giving single figure numbers for our fertiliser recommendations as dictated by my boss - "you are the expert, Bill so do not dodge your responsibilities, tell them how much to use". Rather we should offer options and sensitivity analyses. "You could do this, this or this and if you have this sort of season and these prices then your returns will be x, y or z depending on how much you intend to apply." And "this is the return to fertiliser for these different rates of application dollars and if you have this sort of season the sensitivity curves will vary in this way from if you have that sort of season!".

The best use of our scientific input is to point out options (normally obvious) and then provide information in a way which answers the "what happens if…?" questions. My comfort from applying this type of philosophy was that, if I offered a wide enough range of options and outputs, the grower would have to choose one within the range provided. That way, instead of being always wrong (as in the soil testing example above) I could be always right! Not only that, but the decision was back with its rightful owner, the grower/decision maker, who has all the other factors impinging on his expenditure decision, in his head. We have simply given them our information in a form that they can understand and which they can put together with information we do not have at our disposal, but which is very important to their decision.

This approach was used to great effect when the WA government decided (in co-operation with the fertiliser company providing a soil-testing service), to provide free, soil-test based fertiliser advice to farmers in the NE agricultural region who had just come through four years of drought. Their biggest constraint to growing successful crops in a fifth year was not soil testing advice, but simply cash flow to put in a crop and to survive. While the company wanted to provide a single figure "optimum" fertiliser recommendation based on the new and subsidised soil-test information, we at WADA insisted on providing two pages of print-out of options and sensitivity analyses. It was pointed out quite rightly, that 90 – 95% growers did not want such complicated output; ("just tell us what to do") so we guaranteed to school them in its use. We were able to show the consequences in dollar terms of necessarily cutting fertiliser inputs and they were able to take the output to the lending houses to argue their case for further advances of cash – or not, depending on their situation. In the ex-post survey, 70% of users found the two-page output useful.

There is no single "best management package" or single "optimum" solution for any given problem except when that problem or situation is defined in all its biological, physical, economic and social detail. The definition or diagnosis of a situation in this broadest sense is the challenge for people wanting to offer prescriptive advice. Failing that, information has to be delivered in a form that makes it easy for the recipient to put into the computer on top of his shoulders and so make a better informed decision. Advisers should offer their information as options and sensitivity analyses.

Managing in the presence of the unmanageable – i.e., dealing with risk.

What is the value to farmers of better knowledge of the uncontrollable factors of climate and soil properties and the unpredictable factors of price and seasonal conditions?

Water-limited yield potential is the major determinant of the main management decisions related to nutrition, herbicide use, and cultivar choice. Other management decisions (e.g., ripping, row spacing, sowing date, seeding rate) can change yield potential at a given site in a given year. The estimation or prediction of water-limited yield and its variability in space and time has received a lot of effort in WA since the work of Halse (1977 pers.com). Have our predictive skills improved enough so that estimates of yield potential can be useful in decision making for more than a handful of growers?

Unfortunately, because they are God-given, season and soil type are both largely unmanageable without input of resources such as irrigation or amelioration of poor soils. So predictions of yield potential are always subject to the serendipity of the season and how it interacts with spatially variable soils.

In the light of the avalanche of information now overwhelming them in the areas of climate prediction and yield mapping, what are the reasons why growers largely ignore it for management? How good are our predictions when they are based on variables like season and soil type?

Season
Despite the endeavours of our best meteorological minds, the prediction of the season to come is still hopeless from a decision maker's point of view. Certainly, outcomes can be hedged in betting or probabilistic terms (percentiles, decile ratings, boxes and whiskers, "you have a 30% chance of this and a 70% chance of that"), but once you choose the strategy which suits your risk preferences, you are not playing 100 seasons to get the predicted outcome, you are playing only one. And as such you are playing a chocolate wheel – with chances (albeit slim?) that your chosen strategy will lead to a financial wipe-out. Maybe there are other ways of playing the same information such as 'spreading your risks' and/or being more flexible by 'playing the season' as it comes? For some people, having a failsafe option is better than playing the probabilities.

Time-of-break and plans A B and C
The timing of the break is one of the major seasonal variables impacting on crop yield potential and management. Although the time of the break is unpredictable, most of the important crop management decisions are made at or before sowing and so the grower has full information for those decisions at that time. I was educated by a group of farmers at Varley in 1982, to the importance of adjusting their cropping plans for the timing of the break. Those farmers had in place whole-farm cropping plans for A, an early break, B an average break, and C a late break. These plans involved having fertiliser, herbicides and seed for different cultivars and species on hand. Different paddocks and crops would be used in the program according to plans A, B and C. I assume that most farmers now have this sort of flexibility built into their cropping programs simply because you cannot predict when the season will break. If they do not then it should be the first step they take in managing seasonal variability.

Time-of-break and spreading the risks
Choice of cultivar depends markedly on sowing date which in turn is dictated to some extent by the time of the break. For any time of sowing, the "flowering window" concept tries to find a cultivar which makes the compromise between flowering late enough to markedly reduce the risk of frost damage, but early enough to minimise the impact of post-anthesis water stress on grain fill. My worry about current seeding 'packages' is that, in concentrating on a 'flowering window', they have led to more synchronous flowering of crops and thus increased the likelihood of total escapes or total wipe-outs from frost and/or pest invasions.

The concept of 'first opportunity sowing' has been in place since our great grandfathers kept the horses in trim to start preparing the seed beds on the first rains. It came to the fore again in the early '80s with the increased push on herbicides and one-pass seeding. Farmers bought large machinery so that they could seed crops in a minimum of time because of the "myth" (see Fisher et al, 2006) that you would lose 30 to 60 kg/ha grain per day delay in seeding. These losses are true for late-break seasons but are questionable for average or early-break seasons. More synchronous seeding time also leads to more synchronous crop development.

Staggered seeding with standard cultivars also spreads the risk to grain yield of completely unpredictable seasonal finishes. Yes, part of the crop may be wiped out, but other parts could perform well. I have seen enough time-of-sowing trial results to see late-sown treatments out-perform early sown treatments. The results are completely explicable in hindsight but not in looking forward from the break, simply because we do not yet (and probably never will) have the ability to predict the season to come with any certainty. We can generate probabilities and growers can choose their gamble, but I suggest that they may be better off by hedging bets and spreading risks.

Time of break and season to come

An early break gets farmers excited because there is a chance of a good season to come (late breaks can deliver only poor to average seasons). An early break does not guarantee a good season to follow and as such, growers should hedge their bets in management terms unless they have soil types containing stored water from either fallows or significant summer rains.

In 2003, much of the NE wheat belt in WA had an early break. Some growers read the break as the green light for a good season and sowed early with maximum inputs as suggested by high yield-potential packages. Other growers were more cautious. The former group had the best-looking crops all season, but they harvested low yields and very high screenings. The WADA climate group's soil moisture maps for April and May 2003 showed the NE wheatbelt as having very low (<10 percentile of years) stored moisture (as indeed, farmers would know from their local rainfall records or could try to determine from a probe for moisture). It is a real gamble to pull out all the stops without some guarantee of moisture to finish the crop.

Predicting yield potential using growing-season rainfall

There are several levels of entry in this game. They all depend on some projection of the season to come from the good old 'average' through to probabilities of certain season types based on historical records or simulated results. Having come up with a prediction of rainfall (on whatever time step), yield potential is predicted according to different models with different time steps. The problem for the adviser/grower here, is one of what level of approximation is useful for the task in hand? I would suggest that, given the vagaries of the system, for most of them, the models and outputs do not have to be very sophisticated. Some levels of entry are:

1. For wheat grain, I always used 10 kg/ha/mm of growing-season rain. To my mind, if you just want an estimate of what a region could grow, that would be good enough. This level of simplicity is probably good enough for most practical management decision making.

2. The method of French and Schultz 2004) (F-S) adds a soil evaporation component to the previous version. Its introduction was instrumental in getting people to think quantitatively about the truism that yields increase with rainfall and the gap between actual and water-limited yield. I suggest that the F-S model has been misused and abused by some naïve agronomists and advisers.

   The F-S equation originally related grain yield to measured water use, but for wider use, it was simplified to take an input of April to October rainfall as a surrogate for water use.

The equation takes April to October rainfall, subtracts an intercept (110mm) and multiplies the result by a water use efficiency (WUE = 20 kg/mm for wheat) to give an estimate of yield. To better match data, various users then adjust this model. This may be by adding in fractions of pre-April rain or by changing the intercept and slope (WUE), particularly for different soil types, species and regions. All of this is legitimate for some purposes but can get quite out of hand.

A major problem with the use of F-S is assuming that any observed yields that are less than the F-S prediction, are low because of agronomic constraints. This can be far from the truth. Because there is only one number to summarise a whole season's rainfall, the F-S yield prediction does not take account of differences in the distribution of any rainfall input. If simulation models (or real data, Anderson 1992) are to be believed, then F-S predicts yields in the top 95-98 percentile range. And so most yields less than the F-S prediction can occur simply because of the pattern of the season rather than any agronomic constraints. So, unless you have some other evidence of agronomic mismanagement, do not blame growers when their yields do not come up to an F-S prediction! The F-S model also does not take account of excess rainfall which gives runoff and/or drainage. These losses, and yield limitations imposed by radiation and temperature, mean that actual yields in high-rainfall situations fall markedly below the F-S predictions.

The F-S model is too simple to handle soil type, sowing date, temperature, and vapour pressure deficit effects on yield potential (Perry 1987). All these factors can be used to falsify the F-S approach and so another level of complexity is needed for more specific yield predictions.

3. Intermediate models such as those described by Oliver et al. (2009) adjust water availability budgets on shorter timesteps and take account of soil type at a rudimentary level. They convert these water budgets to yield in simplistic ways. All have a role to play for some particular problems. Are they at the appropriate level for of accuracy for your decision making?

4. The final class of yield prediction models that I must mention are the daily time-step simulation models (e.g., APSIM and its commercial version, Yield Prophet ((Hunt et al. 2006) which go well beyond just transforming rainfall data and attempt to simulate how the various crops grow in response to soil type, season and management. Such models can run off yield potentials (and N-constrained yields) for most soil, season, and management situations.

   All these levels of approach only produce probability distributions of potential yields. The problem again in getting useful information out of them, is how to interpret and then use the probabilistic output. If you cannot do this, then you are better playing the season as it comes and hedging bets!

Soil type

Soil type is obviously an important factor in determining yield and yield potential. You need only look at one yield map to see that yields vary markedly for the same rainfall and management conditions. Part of this variation may well be due to run-on and run-off, but studies using soil pit observations, correlations through time and space, and pre-clearing photos have shown that in the WA agricultural areas, it is due largely to soil-type variation. Consistently low or consistently high performing areas on farms are often seen to continue across paddock boundaries and are apparent in the adjacent virgin bush. The original land class mapping in WA was based on the height of the vegetation and this seems to be reflected in the size of crops being measured by yield monitors. Although management differences (e.g., rotation and fertiliser history) between paddocks can be large, the zones seem to transcend them. Much of the effect of soil type on yield is through water relations.

Soil water storage measures

Soil texture, gravel content and bulk density determine soil water-holding capacity which together with crop rooting depth gives the plant available water holding capacity (PAWC or bucket size). Bucket size dictates the potential moisture storage of a soil and interacts with rainfall and evapotranspiration patterns to give the plant available water (PAW) in a soil at any time. If we can characterise these parameters, then we will have gone a long way towards understanding the spatial variation in water limited yield potential.

For example, by using simple calculations, you can explain the different degrees of haying off or maturity in a crop in spring as you move around a paddock. The time between rainfall events before a crop will start to wilt and eventually to die can be approximated for different soil types by knowing simple texture related, soil water storage characteristics (Hamblin 1982).

Can we improve soil water storage?

Crops can acquire more stored water if subsoil constraints such as traffic hard pans or toxic acidity layers are removed to allow greater rooting depth. Also, methods to increase rainfall infiltration will increase stored water content. However, not much can be done to change the moisture storage properties of a soil apart from adding high moisture holding ameliorants such as clay, peat or ash, and/or by building up soil organic matter.

Many agronomists and growers see the retention of organic residues and the build up of soil organic matter as a means of turning poor sands into fertile soils. Though the idea is sound, the process will be very long term because you must grow organic matter to build up organic matter and you have to retain it rather than respire it away. Sandy soils with low clay content do not protect organic matter from break-down very well. It can be a simple matter to improve the surface soils with additions of clay or organic matter, but this can lead to enhanced early growth which cannot be sustained later in the season because the residual stored water is spread to depth in the profile

To lift soil organic carbon (OC) by 0.1% you must retain about 1.5 t/ha carbon per 10 cm of soil. This equates to about 3 t/ha of organic matter and because one half to two thirds of organic inputs are lost to respiration during the break-down of residues and root material, you need to retain 6-9 t/ha EXTRA organic materials to add 0.1% to your existing soil OC% (which is being maintained by your current cropping practices). If soil organic carbon holds 10 times its weight as water (unlikely though some commercial products may), then an extra 1.5 t/ha organic carbon would hold an extra 15 t/ha of water which equates to an increase in water holding capacity (though not necessarily PAWC) of 1.5 mm..

Adding 100 t/ha of clay which, may hold 30% by weight of water, to the soil, will only increase the soil water storage by 30 t/ha or 3mm. However, it may well improve wettability and infiltration and it could well pin a water column to the surface and so reduce leaching through drainage. Deep ploughing to mix subsoil clay with surface sand can change the water distribution in the profile but does little for total store moisture unless soil porosity and/or bulk density is changed significantly.

*So, what is the use of better rainfall and soil type information***?**

Can knowledge about soil-water holding capacity help us in our management? It obviously can, because yield potential determines how we manage crops and particularly, how large the inputs should be. Low yield-potential zones and soils will be dropped out of cropping first if not due to the cost/price squeeze, then certainly due to the encroaching effects of drier seasons associated with climate change. If it rains all the time, bucket size does not matter (except for the leaching of mobile nutrients) – you can produce good crops on shallow soils. However, if you have droughts as we most assuredly do at the end of each season in WA, then soil moisture storage is crucial.

A wheat crop in WA requires 25 stress-free days of linear grain growth between anthesis and maturity to reach potential yield, so each day of no water use reduces yield by 4%. If crops use 4 mm/day in that post-anthesis period of linear grain yield growth, then 100 mm of PAW is needed for the crop to attain yield potential in the absence of rain. Put another way, each mm of stored moisture is worth 1% of yield potential. Removing a sub-soil constraint that blocks root access to another 30 mm of sub-soil moisture can increase yields by 30%. I prefer this method of estimating the value of the stored water because the alternative of say 20 kg/ha per mm of stored water does not account for the fact that large crops use water more efficiently than small crops – An extra day of grain fill on a 4 t/ha crop is worth 4 times that of a 1 t/ha crop.

In the northern and eastern fringes of the WA agricultural areas and on some shallower or heavier soil types, excessive early moisture use by a crop may leave very little soil moisture for grain fill. An analysis of rainfall may show that this happens so consistently that growers should have a management strategy aimed at reducing early vigour of the crop. Such strategies include lower seeding rates, wider row spacing, lower and later N inputs as well as more frequent cropping to reduce soil-N levels. The problem with such strategies is that in good years and on deeper soils, lower early vigour will lead to lower yields than if a big crop had been set up early. Responses to deep ripping in WA illustrate this point. Large, positive, vegetative and grain yield response to deep ripping on soils with traffic pans, are regularly seen in the greater wheat belt of WA. On the eastern and northern fringes, positive vegetative responses are equally as common, but these often do not translate into positive grain yield responses to inputs and can even give negative responses (Farré et al. 2010). Where rainfall is low but PAWC is high, perhaps fallowing becomes an option such that crops use two years rainfall input rather than one. Fallow effects can be positive in a wide range of situations – not just from fallowing heavy soils in wet years. We measured a 0.5 t/ha wheat response in 2003 following brown manuring a dodgy lupin crop in the drought year of 2002 at Northam. The response was evident only when the wheat approached maturity, so it was not an due to N. Neither was it a cleaning-crop effect because other 2002 lupin plots that were taken through to harvest, did not produce the wheat response

In the absence of useful predictions of seasonal conditions, but knowing they are variable, a strategy for using fertiliser N is to fertilise at seeding for yield potential in a decile-3 year and then, if the crop or season looks like it will be significantly better, apply more N as the season progresses. The strategy is to be flexible and play the season if possible. For post-tillering N applications, you would give priority to high yielding areas in the crop paddocks and only in seasons and on soils where PAW is high or promises to be high.

Price variation
It is real, it is largely unpredictable and it is large. About 15 years ago, we ran a series of 15 trials looking at different tactics/strategies for giving fertiliser advice. Our rational economic approach determined an optimum rate based on costs of fertiliser and prices for the crop at the beginning of the year and we determined the most profitable rates after harvest. In the 3 years of the trials, the price of wheat plummeted, stayed the same and rose spectacularly between sowing and harvest, with up to $150/hectare differences in returns to fertiliser depending on which price was used! I will leave it to experts in price hedging to explain how best to manage that uncertainty.

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