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Combining productivity and sustainability: A challenge for the new millenium

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SUMARY – Sustainability in agriculture contains economic, biological and social elements but the cornerstone is economic. Sustainable practices will not be employed in agriculture unless they can be paid for either at the farm or community level. Unless farmers are making secure profits they are unable to invest in sustainable practices, regardless of their desirability. Some approaches to increasing grain yield and grain quality to meet the demands of premium paying markets will be discussed. Some practices that are necessary for biological sustainability and that must be integrated into our cropping systems will also be discussed. They include: soil type selection and management to restore fertility; pest, disease and weed management with minimum use of chemicals; and control of rising water tables and soil salinity through appropriate crop management and use of perennial species.

Key words: Productivity, sustainability, yield, quality.

RESUME – *"Combiner la productivité et la durabilité : Un défi pour le nouveau millénaire". La durabilité en agriculture comporte des éléments économiques, biologiques et sociaux mais la pierre angulaire est économique. Les pratiques durables ne seront pas employées en agriculture à moins qu'elles ne soient rémunératrices soit au niveau de la ferme soit au niveau de la communauté. Si les agriculteurs n'ont pas de bénéfices assurés, ils ne sont pas en mesure d'investir dans les pratiques durables, quel que soit leur souhait. Quelques approches pour l'augmentation du rendement en grain et de la qualité du grain pour répondre aux exigences des marchés rémunérant la haute qualité seront discutées. Certaines pratiques qui sont nécessaires pour la durabilité biologique et qui doivent être intégrées dans nos systèmes de culture seront également discutées. Elles incluent : sélection du type de sol et gestion pour restaurer la fertilité ; protection contre ravageurs, maladies et mauvaises herbes avec une utilisation minimale de produits chimiques ; et contrôle des corps d'eau montants et de la salinité du sol au travers d'une gestion appropriée des cultures et l'utilisation d'espèces pérennes.*

Mots-clés : *Productivité, durabilité, rendement, qualité.*

Background

Increases in grain yield of dryland bread and durum wheat crops since the 1960's have been associated with management practices such as increased use of herbicides, earlier sowing, the use of legumes and other "break" crops in the rotation, increased use of artificial fertilizers, systems of integrated pest management, soil amelioration through deep tillage, gypsum and lime, and the use of cultivar-specific agronomic practices. In dryland wheat growing areas of the world the proportion of yield increases attributed to crop management is often in the range 40-80% (data summarized by Byerlee, 1987). The evidence that practices including reduced or zero tillage and retention of crop residues have increased grain yields is less convincing (Kirkegaard, 1995). Nevertheless, there is little doubt that such practices either reduce costs and/or improve soil conditions over time and should form part of a sustainable cropping system.

The major threats to the long term viability of wheat based cropping systems in the dryland areas include:

(i) Reduction in soil physical and chemical fertility due to increased cropping intensity.

(ii) Acidification related to the use of fertilizers, the growth of legumes and the removal of grain from farms.

(iii) Development of biological resistances due to inappropriate use of chemicals.

(iv) Salinity related to rising water tables.

To varying degrees these problems threaten crop yields and profits. Systems that are developed to produce wheat in the future must recognize these threats and incorporate measures to reduce their impact. Fortunately methods are available, or under development, that can be economically introduced to enable farmers to achieve long term viability in wheat production.

Water use and grain yield

The importance of water use and water use efficiency in dyland wheat production has often been emphasized (Fischer, 1979; Cooper *et al.,* 1987; Anderson, 1992). The key to increasing grain yield in dryland cropping environments has been to remove the constraints that limit the ability of the crop to use all the water available to it (French and Schultz, 1984). Wheat yield can be related to rainfall in the growing season (plus an estimate of stored water, less an estimate of losses due to soil evaporation and deep drainage) such that:

Potential yield = (Rainfall in the growing season – Losses) TE

where TE is transpiration efficiency estimated at 20kg/ha/mm and losses are estimated as the x-intercept of the plot of grain yield on seasonal rainfall.

This concept has provided a tool for measuring the performance of a crop against the rainfall-limited potential yield and thus for identifying practices that can improve yield and water use efficiency.

Using all the water available to the crop is highly desirable, both for increasing yield and for reducing recharge of the water table that may lead to salinization in some situations. Water use efficiency, the ratio of water used to grain produced, is more influenced by yield than by water use. It might be supposed that any practice that improves grain yield automatically increases water use efficiency. Grain yields are largely increased through increasing the transpiration component of water use and reducing the soil losses of water through evaporation or deep drainage. Total water use is seldom changed appreciably between high and low yielding crops (Table 1).

Table 1. Water use characteristics of wheat crops in Western Australia (data are from 7 experiments with rainfall in the growing season varying from 237 to 338 mm)

	Low inputs (June sown, tall cultivar 0 kg/ha N, 50 kg/ha seed)	High inputs (May sown, semi-dwarf cultivar, 50 kg/ha N, 70 kg/ha seed)
Grain yield (t/ha)	2.62	3.62
Total water use (mm)	285	290
Transpiration (mm)	185	240
Water loss (mm)	100	50
Water used after anthesis (mm)	69	86
Water use efficiency (kg/ha/mm)	9.2	12.5

To the extent that losses of water to the crop are due to deep drainage rather than soil evaporation (not separated in Table 1), producing higher yielding crops may reduce recharge of groundwater and subsequent salinity. It is suggested that if farmers concentrate on improving crop yield through management, improved water use efficiency will follow and there is a chance that water lost to the crop through deep drainage will be reduced.

Where the seasonal rainfall is less than about 250-400 mm fallow can increase the water supply available to the following crop and lead to increased yield (Fisher, 1962; Guler and Karaca, 1988; Amir *et al.,* 1991). The variation in the upper limit of rainfall for successful use of fallow appears to depend on soil water storage capacity. However, the advantages of fallow which include increased mineralization of nitrogen and weed and disease reduction, in addition to increased water storage, are likely to be outweighed in many situations by loss of income in the fallow year, increased risk of erosion, reduced soil physical fertility, and/or the risk of herbicide resistance. The practice is unlikely to contribute to the viability in the long term of dryland, wheat based farming systems unless it is practised with minimal soil disturbance and retention of crop residues.

Weed management and early sowing

The use of desiccant and selective herbicides has provided the opportunity to sow the crop earlier. In addition, weed control in the year preceding the wheat crop has allowed growers to sow without delay after the opening rains of the season. The average date of sowing in Western Australia has advanced by 2-3 weeks and yields have increased as a result (Anderson and Smith, 1990). Reduction of weeds with herbicide application in the year before cropping also reduces carryover of root pathogens (MacLeod *et al.,* 1993) and can increase both grain yield and protein percentage (Table 2).

Table 2. Weed control in the year before the wheat crop increases yield and protein percentage (data of C. Thorn, Avondale, Western Australia, 1992)

Treatment on clover pasture in previous year	Wheat yield (t/ha)	Wheat protein (%)
Nil	1.62	12.1
Broadleaf herbicide	2.05	12.1
Grass herbicide	2.64	13.4
Both herbicides	2.91	13.8

Most strategies used to control weeds, so that sowing can be accomplished earlier, involve the use of herbicides. Sowing with machinery that does not require prior cultivation (No-till or zero tillage) can also be used to advance the sowing time, given that operations can begin sooner after a rain event, but the practice is dependent on the use of herbicides. Strategic use of desiccant chemicals before sowing probably has a minimal risk of inducing herbicide resistance in weed populations but ultimately an integrated strategy of weed management must include non-chemical methods as well as herbicides. One means to encourage a more competitive wheat crop is by increasing the plant population (Table 3). Other means could include systems to induce faster seedling emergence and more vigorous early growth.

Table 3. Increasing wheat plant population decreases ryegrass population and seed set and increases wheat yield (data of C. Fee, Merredin, Western Australia, 1996)

Plant population (plants/m^2)		Grain yield (t/ha)		Ryegrass seeds/m^2
Wheat	Ryegrass	-Ryegrass	+Ryegrass	
119	117	3.46	3.00	3187
216	100	3.59	3.29	1817
344	85	3.62	3.46	1203

Integrated weed control systems may use non-residual chemicals, cultivation, highly competitive crops and cultivars, green manure and hay crops, grazing and even burning of crop residues where appropriate. If zero tillage systems are to fulfill their promise of adding to the long term viability of cropping systems in dryland areas the problem of weed control must be solved in a sustainable way that minimizes the risk of developing herbicide resistance.

Rotations, soil fertility and root diseases

Crop rotation is used as a management tool to reduce weeds, pathogens and insects, to improve soil fertility and to stabilize income by spreading risk. Wheat yields in rotation with grain legumes in Western

Australia have been increased by 39 to 46% in experiments compared to continuous wheat (I. Rowland, pers. comm.). Grain protein percentage was also increased by between 1 and 2% in these experiments and in experiments carried out elsewhere in similar environments (Lopez-Bellido *et al.,* 1998). Increases in grain protein due to legume rotation can be about twice those due to management practices such as delayed sowing time, nitrogen fertilizer application, choice of cultivar or grass weed control (Anderson *et al.,* 1998). Yield and protein increases following grain legume crops have been shown to be associated with increases in soil nitrogen (Reeves *et al.,* 1984; Delroy and Bowden, 1986).

The use of crop rotation, including pastures for livestock, is an essential component of wheat production systems in most parts of the dryland, winter dominant rainfall areas. On current evidence it is difficult to envisage a sustainable system that does not include some aspect of crop rotation or some more flexible cropping sequence that contributes to disease, weed and pest management, soil fertility and income stability. Such a system could also incorporate soil renovation, retention of crop residues and reduced or zero tillage.

The use of "break" crops in the rotation has been effective in reducing the impact of root diseases. Broadleaf crops such as canola preceding the wheat crop have been shown to increase grain yield, presumably due to reductions in root disease (Angus *et al.,* 1991). The connection between grass weed control prior to cropping with wheat, reduction in Take All and wheat yield has been clearly demonstrated (Table 4).

Table 4. Relationship between grass weed control, Take All and wheat yield (after MacLeod *et al.,* 1993)

Treatment in previous year	Grass dry matter in previous pasture (t/ha)	Take All		Wheat yield (t/ha)
		Incidence (%)	Severity (%)	
Nil	0.90	20	30	1.10
Grass selective	0.30	7	15	1.95
Spraytop	0.40	10	18	1.85
Broad spectrum herbicide	0.25	5	7	2.10

Soil type, crop type and grain quality

In situations where increasing grain yield by agronomic means is risky, or not possible due to inadequate water supply or unavailability of other inputs, it may be preferable to change the production system to increase the price received. In such cases profitability can be maintained without undue production risks and unsustainable cropping intensity is not likely to be necessary. Most farmers have a limited choice of soils on which to grow the wheat crop. An understanding of the grain quality types that are most appropriate on particular soils is a useful management tool for designing profitable cropping systems. For example where legume rotations are practised in Western Australia on clay and clay loam soils it is easier to produce the higher protein that is required for hard wheat, but on the coarser textured soils it is easier to manage for the medium protein percentages that are required for noodle wheat (Table 5).

Table 5. Soil type affects success rate (%) of achieving specified grain protein levels in two sets of experiments following grain or pasture legumes (data for hard wheat experiments are from N. Kerr, Geraldton, Western Australia)

Soil Type	Noodle wheat experiments (1994-1997) (Protein 9.5-11.5%)	Hard wheat experiments (1993-1995) (Protein > 13%)
Red clay loam	50	70
Brown/grey clay loam	50	50
Duplex†	80	17
Sandplain††	100	22

†Sand over clay at < 50 cm.
††Loamy sand to at least 1 m.

The requirement for grain protein exceeding 13% in durum wheat has lead to a production system in Western Australia that is concentrated on the friable red clay loam soils with neutral to alkaline pH and using a legume based rotation. Research has shown that if this system is used and grass weeds are controlled before the crop year there is generally no economic yield response to additions of nitrogen fertilizer and grain protein exceeds 13% (Impiglia and Anderson, 1998).

The price incentives that are available for grain of the appropriate quality for particular end uses are almost as important for profitability as yield itself. Most of the available evidence confirms that the production of high quality grain does not entail practices that are in conflict with the production of high yields. Selection of cultivars that are acceptable to the market, selection of appropriate combinations of rotations and soils, and adjusting fertilizers, weed control, and plant populations for maximum yield according to the rainfall zone, are all practices that should lead to good quality. Profits can be maintained by improving quality without over-using practices that may lead to increased soil acidity, herbicide resistance and soil structural decline. Quality has thus become linked to sustainability.

Cultivar-specific agronomy

The agronomic practices appropriate for one cultivar may not be appropriate for all cultivars. The clearest example of this effect in wheat has been the response of semi-dwarf cultivars compared with tall cultivars where the yield advantage of the semi-dwarfs may not be apparent unless the agronomic management is appropriate (Table 6).

Table 6. Effect of agronomic practices and cultivar on the yield of wheat (t/ha) in Western Australia (data are from 7 sites where rainfall in the growing season varied from 237 to 338 mm)

	Tall cultivar	Semi-dwarf cultivar	Increase due to cultivar
Old agronomy†	2.62	2.69	0.07
New agronomy††	3.05	3.62	0.57
Increase due to agronomy	0.43	0.93	

†Sown June, 0 kg/ha N, 50 kg/ha seed.

††Sown May, 50 kg/ha N, 70 kg/ha seed.

Matching cultivar maturity to the sowing date is a key element for maximizing wheat grain yields in dryland, winter dominant rainfall regions (Anderson and Smith, 1990). Where long, mid and short season cultivars are available to the farmer, the appropriate cultivar can be selected according to the sowing time thus increasing productivity and reducing seasonal risks. In addition, differences between cultivars can be found in response to inputs such as seed rate (Anderson and Barclay, 1991) and nitrogen fertilizer (Anderson *et al.,* 1991) and increasingly growers are seeking cultivar-specific agronomic information.

Much of the yield improvement in both bread and durum wheat has been the result of the combination of improved agronomy and improved cultivars. Plant breeding has been successful in providing resistance to the leaf diseases where crop management techniques are not available, or less effective by themselves (Loughman and Thomas, 1992). Breeding for resistance to diseases is probably best viewed as a means for stabilizing production rather than increasing it and as such can be a strong contributor to sustainability. Similarly, where breeding improves grain quality it can also be viewed as contributing to sustainability as outlined above.

Fertilizer management

More precise management of fertilizer applications to wheat crops is desirable to increase profits, to reduce soil acidification and nutrient losses from farms. Systems that estimate all components of the nutrient balance and assess the spatial variability of nutrients will ultimately be useful for decision-makers. In practice factors such as the availability of fertilizers and cash, the relative return from other inputs, interactions with factors such as weeds, variable rainfall and the perceived risk to the environment will all modify fertilizer decisions.

Recovery of applied fertilizers by the wheat crop is often low. For example recovery of applied nitrogen seldom exceeds 50,% in dryland wheat crops (Fillery and McInnes, 1992). Improving efficiency of fertilizer use, and probably of fertilizer recovery, can be influenced by several management practices:

(i) Nitrogen and phosphate fertilizers applied to early sown crops are often used more efficiently (Anderson *et al.,* 1995, 1997; Batten *et al.,* 1999; Oweis *et al.,* 1999).

(ii) Banding of nitrogen and potassium fertilizers below and at some distance from the seed often achieves better results than broadcasting (Nyborg and Hennig, 1969).

(iii) Deep placement can have advantages over shallow placement (Jarvis and Bolland, 1990).

(iv) Split applications of nitrogen fertilizers can be most effective in longer season environments or where leaching is likely, leading to increases in grain yield and protein (Mason, 1975).

(v) Some cultivars may have greater recovery efficiency associated with either increased yield or protein efficiency (Anderson and Hoyle, 1999).

(vi) Soil testing, particularly for potassium and phosphorus, can often be used as a reliable guide to optimal fertilizer use (Peverill *et al.,* 1999).

Conclusion

Removal of all the factors that limit complete use of all the water available to the wheat crop in a dryland environment will maximize grain yield and water use efficiency. Maximizing grain yield by these means is rarely detrimental to grain quality. Modifying the production system to produce a higher value product such as durum, noodle wheat or high protein bread wheat can maintain profits and contribute to sustainability.

Cropping systems based only on these principles however, will also need to have the following features if they are to remain viable for the long term:

(i) Minimal, or greatly reduced tillage.

(ii) Retention of crop residues.

(iii) Periodical addition of organic matter from pasture or green manure crops.

(iv) Management of soil acidification (lime).

(v) Management of soil crusting and compaction (gypsum).

(vi) Integrated weed management with minimal use of residual herbicides.

(vii) Disease management through a combination of genetic and cultural means (rotation).

(viii) Use of perennial species to reduce recharge of water tables and the spread of salinity.

(ix) Improved systems of nutrient management to reduce losses off-farm.

(x) Increased use of risk management strategies including crop rotation, use of a range of cultivar maturities, tactical use of inputs according to seasonal conditions, and use of cultivar-specific management.

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