Metrics for evaluating intercropping in broadacre farming systems

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Abstract

Research into and adoption of intercropping is increasing in recent years within broadacre agricultural systems such as in Australia. Intercropping systems are biologically and logistically complex, leading to variable results and making evaluation compared with monocultures difficult. We reviewed existing metrics used to evaluate the relative advantage of intercropping systems and discussed their strengths, limitations, and identified knowledge gaps. The commonly used metrics focus on yield advantage and assume that both component crops and the management complexity are equal. As a consequence, these metrics assume the costs between intercropping and monocropping systems are similar and fail to account for production risk and growers' risk preferences. We propose a comprehensive set of metrics that accommodate all these factors.

Keywords

Sustained productivity, diversification, broadacre-agriculture, economic value.

Introduction

Intercropping is the practice of growing two or more crops simultaneously in the same field for the entire or a part of their growing period. Intercropping is proposed as a potential cropping system that enables greater production from the same or fewer inputs whilst maintaining or enhancing natural ecosystem services (Dowling et al. 2021; Tilman 2020). Intercropping has been widely practiced in smallholder agricultural systems and found to increase resource use efficiency, improve agricultural productivity, reduce business risk, and reduce negative externalities compared to monocultures (Bedoussac et al. 2015; Tilman 2020). Alongside the claimed benefits however, there are challenges in the implementation of intercropping systems in terms of weed control, harvesting, and grain separation (Bedoussac et al. 2015; Mamine and Fares 2020). In recent years, research into and adoption of intercropping has increased in large-scale, technologically advanced, broadacre agricultural systems (Bybee-Finley and Ryan 2018). This is occurring from a low base in Australia; where mixed inter-row and strip cropping is practiced on 104,700 ha across Victoria, and 359,700 ha Australia-wide, which equates to 1-2% of the area cropped (ABS 2018).

Intercropping systems are adopted with different grower objectives. The choice of crop species in the mixture, the proportion of each species depends on the requirements of growers and industry. Consequently, the method employed in evaluating intercropping systems in one context might not be appropriate in another. For intercropping systems to be adopted more broadly within broadacre agriculture, clear production and economic advantages over the current monoculture systems need to be demonstrated. It is relatively easy to compare the outputs of cropping systems that produce similar products and use similar resources including labours. However, intercropping systems have different resource dynamics compared with monocropping systems, thus introducing complexity in evaluating intercropping systems.

We reviewed existing methods used in assessing the advantages of intercropping systems. We propose metrics that are applicable to examine yields, values, and profits from intercropping within broadacre agriculture.

Review of intercropping metrics

Several methods have been used to evaluate intercropping systems, with most studies using Land Equivalent Ratio (LER) to determine if an intercrop is more advantageous than its respective monocultures (Dowling et al. 2021; Lithourgidis et al. 2011). The LER is an index that describes the relative land area required to grow the same quantity of both crop species in the mixture of species 1 and 2, if they were grown as monocultures rather than as mixtures. If the LER is greater than unity, intercropping is preferable. Although the LER is based on land area, it is often interpreted as a measure of relative yield of the crop mixture over its monoculture. Practical interpretation of the LER requires relative yield of component species and absolute yield of monoculture species. Implicit in the LER calculation is the assumption that each species is of equal weight or unit value therefore it is useful if the value of each species is identical, but invariably this is not the case except for variety mixtures. A further limitation of the LER is its inability to reflect the absolute yields as this is calculated relative to monocropping yields. Species mixtures with the highest LER values do not necessarily have the highest absolute total yield (Jolliffe and Wanjau 1999; Bedoussac et al. 2015).

Other yield-based measures include land-equivalent coefficient, crop performance ratio, relative yield of mixture and system productivity index. Despite the method of evaluation, the underlying basis of these methods is always a comparison of yield of the intercrop to the monoculture. If the adoption of intercropping enhances benefits beyond yield such as environmental benefits, an intercropping system with LER <1 may be preferable. Similarly, if an intercropping system requires more external resources (e.g. labour, machinery etc), LER >1 might not be economic. Furthermore, a common limitation of these measures is their assumption of equal market value of the two species in the mixture.

Francis (1986) proposed crop equivalent yield (CEY), a measure that standardizes the yield of the component crop 2, in terms of crop 1 based on the market prices of produce. However, Vandermeer (1992) suggested that when a producer factors in monetary value, the intercrop should be compared to the most valuable of the two monocultures. Such an index is named ‘relative value total’ (RVT) and measures the relative value from the intercropping system compared to that of the most valuable of the two monocultures. These metrics assume the same level of input use and management complexities, hence equal on-farm and post-farm costs for intercropping and monocropping systems. In recent years, studies have increasingly compared economic returns, as measured by the difference between the activity gross margin (GM) of the intercropping and monocropping systems (Roberts Craig 2011).

Selecting appropriate intercropping metrics

Considering the different methods of evaluating crop mixtures, the choice of methods depends on the objective of the enterprise in adopting the crop mixture strategy. If the objective is to maximise production (yield) for a particular mix of species, comparing the total yield from the different cropping systems using the Yield Ratio (YR) (Table 1) is logical. The YR specifies a similar enterprise mix ratio for the mixture and the monocultures. For example, 50:50 ratio is two hectares of mixture compared to one hectare of first monoculture crop plus one hectare of second monoculture. Similarly, a 25:75 ratio is four hectares of mixture compared to one hectare of first monoculture crop plus three hectares of second monoculture.

If the objective is to maximise gross returns (income), comparing the total value of production from different cropping systems becomes important. In such a case, the Value Ratio (VR) would be an appropriate metric. Alternatively, if the objective is to maximise profits, we suggest comparing the net returns from different cropping systems, and Net Gross Margin (Net GM) would be an appropriate metric. When both the intercrop and monocrop have positive gross margin, Profit Ratio (PR) can be calculated to make comparison between the two systems. Interpretation of the VR and PR require value and costs of mixture components and monoculture at the given enterprise mix ratio.

If land is the most limiting factor of production and the objective is to reduce or “spare” land, we suggest using the LER. If other factors of production such as labour costs and water are the major constraints of crop production and the objective is to increase labour and water productivity, then, labour equivalent ratio and water equivalent ratio can be calculated using a similar concept as LER.

Table 1. Evaluation metrics based on the objectives of adopting intercropping systems. Example are for a two species intercrops.

Objective	Method	Decision criteria
Reduce or spare land compared to the current yield from monocultures	$\mathit{Land\ Equivalent\ Ratio}\ (LER) = \frac{Y1_c}{Y1_m} + \frac{Y2_c}{Y2_m}$ … (Eq. 1)	LER>1 indicates intercropping advantage.
Maximize production per hectare (yield) accounting for enterprise mix ratio	$\mathit{Yield\ Ratio}$ (YR) $= \frac{(Y_{1c}+Y_{2c})}{(Z1_C*Y_{1m}+Z2_C*Y_{2m})}$ … (Eq. 2)	YR>1 indicates intercropping advantage.
Maximize expected gross income per hectare	$\mathit{Value\ Ratio}\ (VR) = \frac{(Y_{1c}*P_1+Y_{2c}*P_2)}{(Z1_C*Y_{1m}*P_1+Z2_C*Y_{2m}*P_2)}$ … (Eq. 3)	VR>1 indicates intercropping advantage.
Maximize expected net income (profits) per hectare	*Net Gross Margin (Net GM)* $= GM_c - GM_m$ … (Eq. 4)	Net GM > 0 indicates intercropping advantage.
	$GM_c = [\{(Y_{1c} * P_1 + Y_{2c} * P_2) + Z_o\} - C_3]$	PR>1 indicates intercropping advantage.
	$GM_m = [\{Z1_C * (Y_{1m} * P_1 - C_1)\} + \{Z2_C * (Y_{2m} * P_2 - C_2)\}]$	
	$\mathit{Profit\ Ratio}\ (PR) = \frac{GM_C}{GM_m}$ … (Eq. 5)	

Where Y_{1c} or Y_{2c} = Expected yield of crop 1 or 2 as a intercrop; Y_{1m} or Y_{2m} = Expected yield of crop 1 or 2 as a monoculture; $Z1_c$ and $Z2_c$ = proportional sown area of crops 1 and 2 in the intercrop; P_1 and P_2 are the expected market prices of crops 1 and 2; C_1, C_2 and C_3 are the variable costs of production for crop 1, crop 2 and intercrop plots respectively; Z_o is the value of benefits other than yield from intercropping system; GM_c = Gross Margin from intercropping, GM_m = Gross Margin from monoculture with same enterprise mix as in the mixture.

Although intercropping is thought to mitigate production risk, none of the above metrics accommodate yield and price risk and risk aversion by the decision-maker. Statistical dominance techniques and Certainty Equivalents (CE) derived from cumulative distribution functions of the Net GM can be used to unambiguously rank a set of alternative intercropping systems (Hardaker et al. 2004). Such analysis requires biophysical modelling to extrapolate observed empirical response of crops beyond the specific locations and seasons where the field experiments originally took place.

Besides yield, value and direct, short-term private costs and benefits on-farm, it is also important to consider indirect, long-term and public costs and benefits of adopting intercropping systems, especially if the former is negative. The analysts' focus should not only be on increasing the biomass and yield in the short term, but also on how the adoption of intercropping can enhance environmental services and longer-term improvements in productivity.

Conclusion

The goals and the conditions of an intercrop are context specific and the choice of evaluation methods depends on the researchers'/growers' objectives. Though LER is a good measure of how efficiently the given land area is utilized by an intercropping system compared to a monocropping system, LER alone does not adequately assess relative advantage of intercropping in large-scale, technologically advanced, broadacre agricultural systems such as in Australia. Evaluation of intercropping advantages should consider not only yield outcomes but also associated prices and changes in costs. To compare like with like, an enterprise mix ratio should be specified explicitly for all yield, value, profit and risk metrics.

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