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A framework for assessing peaola land and nutrient use efficiency in the field

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Active pea nodule growing in close proximity to canola roots.

Canola and pea intercropping (peaola) promises a number of benefits that could improve the efficiency and resilience of dryland agricultural systems. Using the correct methods for assessing these intercropping systems is important for determining whether or not an intercropping method is suitable in a particular instance. This article describes methods to assess two of the most common resource use efficiencies: land and nutrients.

Canola and pea intercropping (peaola) promises a number of benefits that could improve the efficiency and resilience of dryland agricultural systems. Using the correct methods for assessing these intercropping systems is important for determining whether or not an intercropping method is suitable in a particular instance. First, it is important to assess whether or not the benefits of intercropping can cover the additional expenses of implementing the intercropping system. Intercropping should also be assessed for its resource use efficiency and ecological impacts compared with monoculture cropping. This article describes methods to assess two of the most common resource use efficiencies: land and nutrients.

Assessing Land Use Efficiency

Calculating Relative Yields

Land use efficiency is one of the primary means by which intercropping yields can be compared with monoculture yields. The Land Equivalent Ratio (LER) is the standard

metric for comparing monocultures to intercrops on a land use basis. The LER is calculated by summing the relative yields for each crop in the intercrop. The relative yield of each crop is calculated by dividing the yield of a particular crop in an intercropping setting by the yield in the same crop grown in monoculture (Equation 1). Using this method, the LER of any intercrop can be calculated no matter how many different crop species are included in the intercrop. In the case of a pea, lentil, and canola intercrop, the LER would be calculated by simply adding the relative yield of lentils (lentils intercropping yield / lentil monoculture yield) to the LER calculation for peaola.

$$(1)\quad LER = \frac{\text{Pea intercropping yield}}{\text{Pea monoculture yield}} + \frac{\text{Canola intercropping yield}}{\text{Canola monoculture yield}}$$

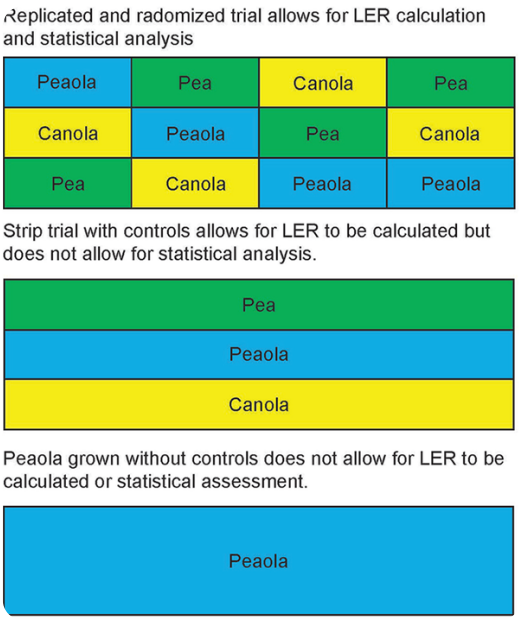


Figure 1, *Experimental designs for assessing intercropping.*

This method of calculating LER was developed for assessing the land use efficiency of intercropping systems in small-plot research experiments. In small-plot research experiments, both the intercrop and the monoculture are grown side by side to allow for an accurate assessment of LER (Figure 1). Additionally, the small plot size allows for replication of both the intercrop and the monoculture controls. The replication allows for statistical comparison of the monoculture to the intercrop. However, in some instances, CCAs may desire to assess the LER of intercropping and monoculture

systems without the added effort of designing a replicated experiment. In these instances, adjacent or nearby fields of monoculture may be used to calculate the relative yields and LERs. For example, if growers are interested in assessing the LER of a peaola system on their land, they could plant a strip of peaola into a canola field and use the average yield of the canola field as the monoculture to calculate the relative canola yield. However, the LER cannot be calculated from the relative canola yield alone. If there is a nearby pea field, the average yield from the pea yield can be used as the monoculture to calculate the relative yield of the peas. If no adjacent or nearby fields are available, county averages or grower experience can be used to calculate the LER. However, it is important to recognize that using these numbers will introduce greater error into the LER number and may lead to an over or underestimation of LER. The closer in spatial proximity the monoculture controls are to the intercrop, the more accurate the LER that can be developed.

Interpreting LER

The LER of monocultures will always equal 1. The LER of intercrops, however, may be above or below 1. An LER greater than 1 indicates that the intercrop system outyields the monoculture system on a per-acre basis. Put another way, the monoculture yield of "Crop A" in a particular situation is considered the 100% mark for the yield of that crop. An intercrop in the same situation may only produce a yield of 75% of Crop A relative to the monoculture of Crop A, but the intercrop system will also produce a yield of "Crop B," which may bring the total intercrop yield relative to the monoculture yield above 100%. For example, in a small-plot winter peaola trial conducted in eastern Washington in 2020, the average monoculture yields of canola and peas were 2,200 and 2,800 lb/ac, respectively. In the intercrop, the average yield of both canola and peas was 2,000 lb. In other words, within one acre, the peaola intercrop produced a total of 4,000 lb of yield on average (2,000 lb from canola and 2,000 lb from pea)

compared with 2,200 or 2,800 lb of yield per acre in the canola and pea monocultures, respectively. For this scenario, the resulting LER was 1.62 (Figure 2). Therefore, on a per-acre basis, the peaola system is shown to have 162% productivity.

A number of small-plot trials, large-scale strip trials, and field-scale observations of peaola have been made. On average, peaola has been shown to have a higher LER than the monocultures. In a review of oilseed–legume intercropping, reported LER results from 15 peaola intercropping trials ranged from 1.1–1.82 (Dowling et al., 2021). With such a wide range of LERs reported in the literature, it will be important for CCAs and other professionals to carefully develop best management practices that maximize the relative increase in productivity. The LER, when used to assess intercropping systems, is limited to assess the gross productivity on a per-acre basis and does not incorporate any differences in the price of the two commodities. A large price difference between the two commodities can completely negate the economic benefits of overyielding.

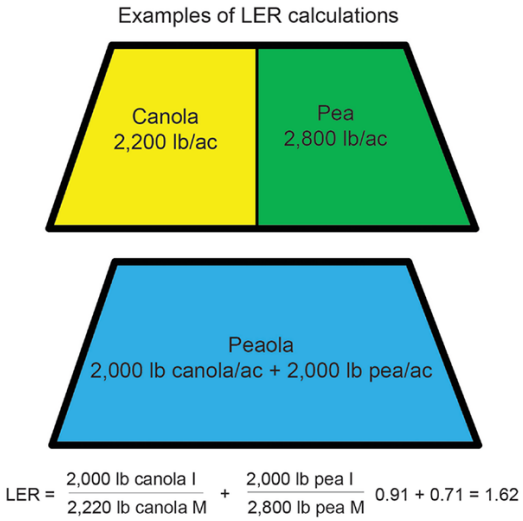


Figure 2, *Example of peaola and canola Land Equivalent Ratio (LER) calculations. In this example with one replication of each, no statistical significance can be attributed to the improved LER. However, a trend toward higher LER in the intercropping system is observed.*

Assessing Nutrient Use Efficiency

One of the primary reasons for implementing peaola intercropping is to take advantage of the N fixing ability of peas. There is a great deal of interest in understanding the in-season transfer of N from the peas to canola. While some in-

season transfer is expected, it is unlikely that agronomically significant quantities of N are transferred from the pea to the canola (Génard et al., **2016**; Jamont et al., **2013**). However, there is preliminary evidence that suggests the peas fix more atmospheric N in the presence of canola than when grown in monoculture (Bremer & Greer, **2021**). It is well known that legumes increase N fixation when soils are low in N (Peoples et al., **1995**). Canola is also known to be an effective N scavenger (Maaz et al., **2016**), which may cause the peas in peaola to increase N fixation. Further investigations of this process are required in the scientific literature. However, the agronomic effects of peaola may be assessed in the field by CCAs using basic calculations of the overall N and fertilizer use efficiency of the system. Nitrogen use efficiency can be calculated by dividing the yield by the pounds of N supply (Equation **2**; Maaz et al., **2016**). Nitrogen supply includes an estimation for mineralization from the soil, mineral N present in the soil (ammonium and nitrate), and N fertilization (Equation **3**). If soil testing is unavailable or deemed too expensive, fertilizer use efficiency may be used instead of nitrogen use efficiency. Fertilizer use efficiency is calculated by dividing the yield by the fertilizer (Equation **4**).

$$\text{Nitrogen use efficiency} = \frac{\text{Total peaola yield}}{\text{N supply}} \quad (2)$$

$$\text{N supply} = \text{Mineralized N} + \text{Mineral N} + \text{Fertilizer N} \quad (3)$$

$$\text{Fertilizer use efficiency} = \frac{\text{Total crop yield}}{\text{Fertilizer N supply}} \quad (4)$$

As mentioned above, the in-season N contributions of the peas to the canola are unlikely to result in agronomically significant additions of N. Therefore, the in-season N or fertilizer use efficiency are unlikely to reflect the full benefits of peaola in rotation. A more complete assessment of these benefits can be carried out by calculating the

rotational N and fertilizer use efficiencies. The rotational fertilizer or nutrient use efficiencies allow for longer-term, more complete assessments of the benefits of peaola. The rotational N use efficiency should be calculated as the sum of the nitrogen use efficiencies of the peaola and the following crop (Equation **5**). To calculate the rotational N supply, soil samples need to be taken before both the peaola and the following wheat crop to calculate the N supply for both crops. Similarly, the fertilizer use efficiency can be calculated by adding the fertilizer use efficiency from both parts of the rotation (Equation **6**).

$$\text{Rotational nitrogen use efficiency} = \frac{\text{Total peaola yield}}{\text{N supply}} + \frac{\text{Wheat yield}}{\text{N suppy}} \quad (5)$$

$$\text{Rotational fertilizer use efficiency} = \frac{\text{Total peaola yield}}{\text{Fertilizer N supply}} + \frac{\text{Wheat yield}}{\text{Fertilizer N supply}} \quad (6)$$



Winter peaola in early May. Canola bolts early closely followed by the peas extending and climbing up the canola plants.

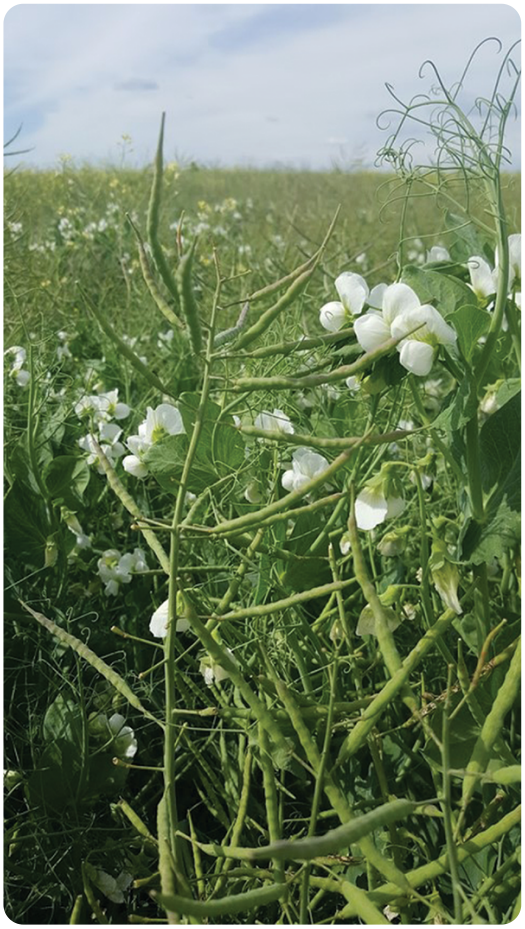
If utilizing the rotation fertilizer use efficiency, the N rate for the following crop should be calculated using an estimation of mineralization from soil organic matter and mineral N in the soil. It is important that the soil test data are used to capture the contributions for the N from the peaola to the following crop. Methods for calculating an N rate using soil test and rotational data are available from a variety of university extension services. Even when N fertilizer rates are calculated using soil test N, some of the N contributions of peaola may not be accounted for as not all of the N contained in the pea biomass will have been mineralized.

Assessing Resilience

“Resilience” is defined as a system’s resistance to or recovery from negative shocks. Examples of these shocks include drought, temperature extremes, pest outbreaks, and increased input costs. Preliminary data from the Inland Pacific Northwest suggests that the LER of peaola may be more stable in the face of adverse circumstances such as drought when compared with monoculture pea and canola. In the fall of 2020 and spring of 2021, the Pacific Northwest experienced severe drought. A winter peaola study conducted in both 2019–2020 and 2020–2021 growing seasons resulted in a significantly greater LER during the drought year (LER = 1.66) than the non-drought year (LER = 1.49). A late-June heat wave prematurely terminated bloom in both the monoculture and intercropped peas. The termination of bloom resulted in a crop failure for peas across both systems. However, the canola in the peaola system had finished flowering by the time the late-June heat wave arrived, providing a chance for at least some yield in the peaola system (Madsen et al., **2022**).

Resilience of intercropping systems can also be assessed by farmers and CCAs on-farm. Assessments of resilience are uncommon in the literature as in many cases they depend on the random chance of a

negative shock. However, in some instances, negative shocks may be simulated as in the case of drought or spikes in input costs. As stated in the example above, if a heat wave occurs during a peaola trial, comparing the peaola LER to the monoculture LERs can give insight into the performance of the intercrop during heat stress compared with a monoculture. However, if the heat wave did not occur, fewer inferences about resilience can be made. Paying attention to differences in factors such as plant growth and pest pressures between peaola and monocultures of pea and canola is another method to assess resilience within the growing season. In order to assess the resilience of an intercropping system over space and time, the monoculture checks must be present in comparable space and time. Average county yields generally cannot be used to effectively assess resilience across space or time.



Winter peaola in late June. At this stage, the canola is actively filling pods while the pea vines have climbed to the top of the canola canopy and continue to flower.

Conclusion

A number of studies suggest that peaola production can result in overyielding compared with monoculture systems. Preliminary evidence also suggests that integrating peaola into cropping systems may result in improved nutrient use efficiency and resilience to stresses. Though not discussed in this article, peaola systems also have the potential to provide a number of other ecological benefits,

including improved soil health, increased microbial diversity, and increased arthropod diversity. Even though recent research is promising, there are a number of challenges that need to be addressed prior to the widespread adoption of peaola. These challenges include the complexity of the operation and reductions of available herbicides that can be used while growing peaola. Other unknowns regarding the best management practices for peaola include seeding rates, fertilizer applications, and relative seed placement. Given the correct frameworks for evaluation described in this article (including LER, N use efficiency, and resilience to negative shocks), CCAs can help to fill these research gaps and contribute to the overall understanding of peaola by assessing the agronomic suitability of peaola in their particular location.

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