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Crop Management – how does it affect the performance of intercrops?

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Summary

Intercropping typically results in a higher yield than those of the individual crops. While appropriate management is vital to get the best performance from any crop, this is especially true for mixtures where strategies must account for the management of two contrasting crops and also for any interactions between them. However, developing management recommendations for intercrops is complex because of the high degree of variation in the findings of published studies and the number of different management strategies available, which depend on the components of individual mixtures. The aim of this work was to examine the effects of management options of cereal species and variety, and pea variety, on the relative performance of cereal/pea intercrops, with a longer-term objective of incorporating them in more diversified and resilient agro-ecological arable cropping systems less dependent on external inputs.

Key words: Wheat, Barley, Oats, Pea, land equivalent ratio, crude protein

Introduction

The need to sustainably intensify crop production and to increase the production of protein are two of the main challenges facing European agriculture. One cropping system that potentially addresses both issues is intercropping, the simultaneous cultivation of two or more crops on the same area of land at the same time. On a global scale, non-maize based intercrops tend to be 20% more productive than sole crops for a given land area (Li *et al*., 2020), thus addressing the need for increased production from existing agricultural land. If the intercrop contains a N-fixing legume then the N fertiliser requirements of the other intercrop component will be reduced by 19% (Li *et al*., 2020). Furthermore, the legume component will help increase the overall protein offtake of the crop, particularly if the legume grown is a grain legume.

In European agriculture the predominant intercropping system is a combination of a cereal with a grain legume (Voisin *et al*., 2014) and the commonest combination is barley (*Hordeum vulgare*) grown with pea (*Pisum sativum*) (Hauggaard Nielsen *et al*., 2009). These systems are characterised by relatively low inputs but are also relatively low yielding. They are grown in rows as mixtures that are sown and harvested at the same time and are particularly common in organic production systems (Bedoussac *et al*., 2015).

A key practical challenge to increase the use of intercrops in Europe is to design optimised and locally adapted management practices for species mixtures. While appropriate management is vital to get the best performance from any crop, this is especially true for mixtures where strategies must account for the management of two contrasting crops and also for any interactions between them. However, developing management recommendations for intercrops is complex because of the high degree of variation in the findings of published studies and the number of different management strategies available. Perhaps the most important and fundamental of these is the choice of species to intercrop, and within that, the choice of variety.

Existing reviews of the effects of management on intercrops are very broad in the types of intercrops that they consider (Yu *et al*., 2016; Pelzer *et al*., 2014). While both studies provide valuable insights into overarching management principles, they inevitably contain a large degree of variation that masks some of the less distinct trends. An approach that appraises studies on a more restricted intercrop combination grown under one climatic regime might produce more specific information on management effects.

One common feature across the majority of the intercropping literature is the use of land equivalent ratio (LER) as an indicator of performance. LER is the sum of partial LERs (pLER). These are the ratios of the yield of one species in an intercrop to its yield as a sole crop, and have been used as an indicator of the relative performance of each component of an intercrop. As such it provides an estimate of the efficiency of land use with an LER greater than one indicating that the intercrop uses land more efficiently than a sole crop.

This paper presents a literature review of the effects of selected management factors on the performance of cereal/pea intercrops under cropping conditions relevant to Europe. The management factors selected were variety of pea, and species and variety of the cereal components of the intercrop. The cereals selected were barley, wheat (*Triticum aestivum*) and oats (*Avena sativa*). LERs for both grain yield and crude protein (CP) yield are used as indicators of performance of the intercrops relative to their sole cropped species. Results are discussed in relation to using intercrops as part of more diversified and resilient agro-ecological arable cropping systems less dependent on external inputs.

Materials and Methods

Paper selection

The "all database" option in Web of Knowledge (WoK) was used to identify the papers for review, using the search terms:

((("cereal pea" OR "pea cereal" OR "pea with cereal" OR "cereal with pea" OR "cereal and pea" OR "pea and cereal") AND (intercrop* OR mix* OR bicrop* OR bi-crop* OR (bi AND crop)) NOT (genomi* OR tropical OR africa*))

Where cereal was substituted by barley, oat and wheat.

The date of the search was 25 June 2019 and after removing duplicates 343, 255 and 363 barley, oat and wheat papers respectively were identified as potentially relevant. To be relevant for the study, the papers must contain data on field experiments that assess the effect of management on cereal/pea intercrops. Thus, literature reviews, pot experiments and papers which focused solely on modelling were excluded. The studies must also be relevant to European growing conditions, although not necessarily have taken place in Europe. At this stage the papers were retained or rejected after reading the title and/or abstract. After scanning the titles and abstracts, 72, 71 and 64 papers were identified as potentially containing information on the effect of management on barley-pea, oat-pea, wheat-pea and intercrops respectively. After reading the papers, 19, 10 and 6 papers contained extractable data for the barley, oat and wheat intercrops respectively (see Table 1).

Analysis

The land equivalent ratios (LERs) were calculated for the experiments for which the yields of the individual sole crop and the components of the intercrop were available. To calculate LERs, all yield data were converted to tonnes per hectare dry matter. The same process was used to calculate the CP land equivalent ratios (CPLERs). Protein data in most papers was usually derived from analysis of N content multiplied by 6.25. Wheat data from Pelzer *et al*. (2016) was originally converted using a factor of 5.7 but to allow better comparisons here it has been recalculated using a factor of 6.25. Gronle *et al*. (2015) used protein contents derived from near infrared (NIR) analysis. The data manipulation was all performed in R (R Development Core Team, 2008), and the ggplot2 package (Wickham, 2016) has been used to create the graphics.

Table 1. *The number of data records captured from each of the selected references*

Author	Number of Records	Author	Number of Records
Barillot *et al*., 2014	7	Lithourgidis *et al*., 2011	10
Baxevanos *et al*., 2017	15	Mason & Pritchard, 1987	6
Chapagain, 2014*a*	5	Monti *et al*., 2016	26
Chen *et al*., 2004	12	Musa *et al*., 2010	5
Corre-Hellou *et al*., 2006	15	Neugschwandtner *et al*., 2014	10
Dordas *et al*., 2012	7	Neumann *et al*., 2007	52
Ghaley *et al*., 2005	8	Ogorek *et al*., 2019	21
Gilliland & Johnston,1992	18	Pappa *et al*., 2012	5
Gronle *et al*., 2015	24	Pelzer *et al*., 2012	75
Hauggaard-Nielsen *et al*., 2001	76	Pelzer *et al*., 2016	16
Hauggaard-Nielsen *et al*., 2006	12	Podgorska-Lesiak *et al*., 2013	45
Hauggaard-Nielsen *et al*., 2008	28	Rauber *et al*., 2001	24
Izaurralde *et al*., 1990	19	Robinson, 1960	42
Jannoura *et al*., 2014	9	Salawu *et al*., 2001	4
Jensen, 1996	24	Strydhorst *et al*., 2008	13
Kontturi *et al*., 2011	90	Tortorella *et al*., 2013	7
Kwabiah *et al*., 2005*a*	9	Tsialtas *et al*., 2018	15
Lauk & Lauk, 2008	21	Uzun & Asik, 2012	15
		Grand Total	790

Results

Summary of the data

The data capture exercise generated 790 individual data records, where each record was a unique combination of site, year, cereal and/or legume species, seed ratios, sowing pattern and N fertiliser.

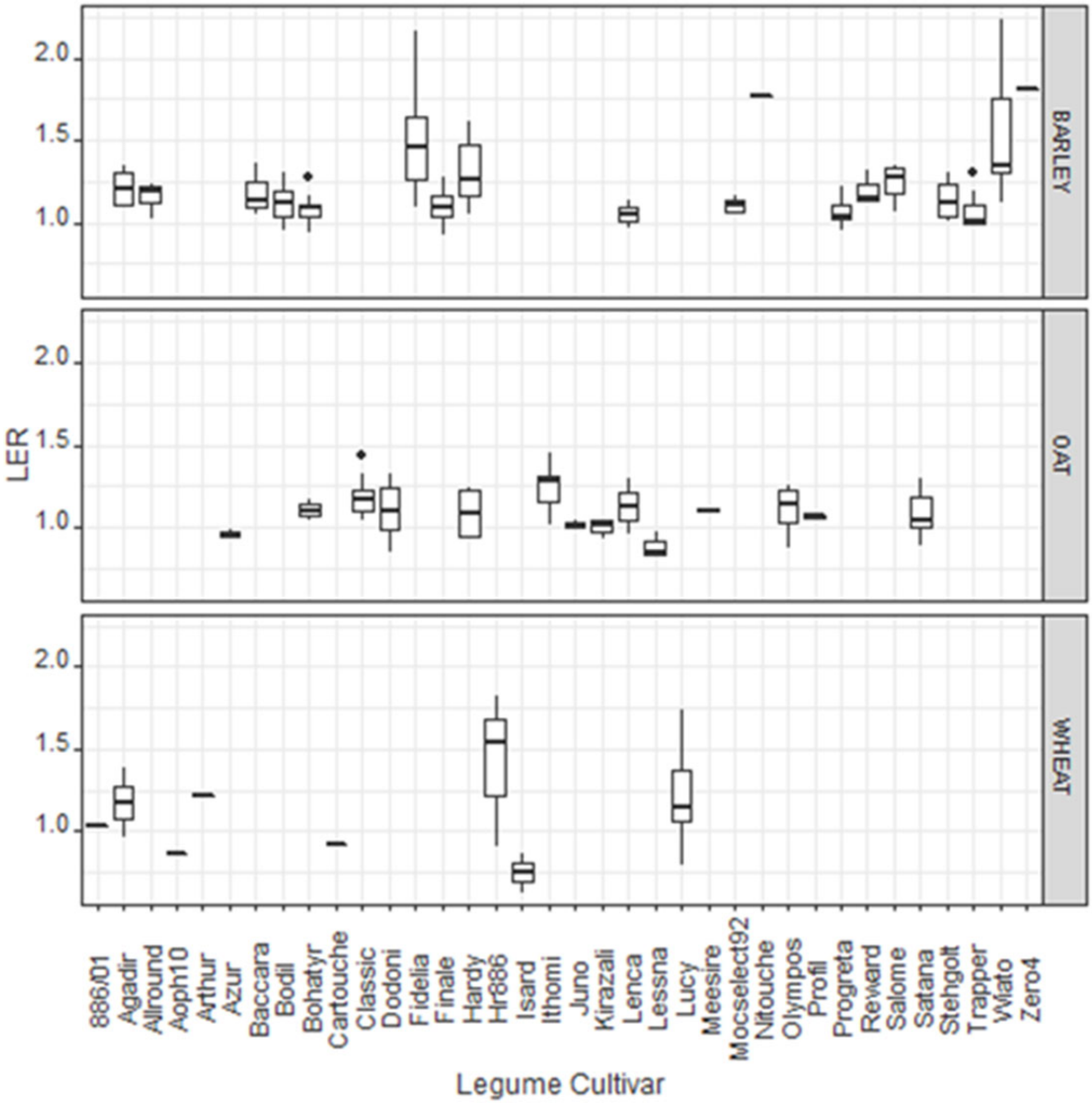

Fig. 1. Boxplots summarizing the LER of the intercrops for barley, oat and wheat by legume variety. The solid horizontal line within a box represents the median value.

This includes sole crops (319 records) and intercrops (471) and the number of records captured from each of the 36 selected papers is shown in Table 1. The majority of records related to intercrops of pea with oat (194), barley (184) or wheat (63), but other cereal/grain legume (30) intercrops were also captured where these were from studies that compared their management. Data came from studies in 14 countries, 11 in Europe (387 records), sown between 1955 and 2012. Most records reported data from 1 year (325) but some averaged data over 2 (92) or 3 (46) years. Where specified, the majority of records were from non-organic systems (321/366) and grown for the grain market (252/349) rather than for forage/silage. No N fertiliser was applied in just over one third of the records where the fertiliser input was specified. About 50% of records showed a low (<65 kg N ha^{-1} yr^{-1}) level of N fertilisation and about 10% received a higher amount (>65 kg N ha^{-1} yr^{-1}).

Within the database, for experiments receiving a low level of fertilisation, there were 36 varieties of peas that have been grown with either barley, oats or wheat (Fig. 1). Typically, the intercrops of barley and pea had a higher median LER (1.14) than either the oats (1.09) or wheat (1.10). However, the range in the wheat LERs was greater than the oats. In contrast, the median LERs for CP were higher for wheat (1.31) than oats (1.18) or barley (1.15).

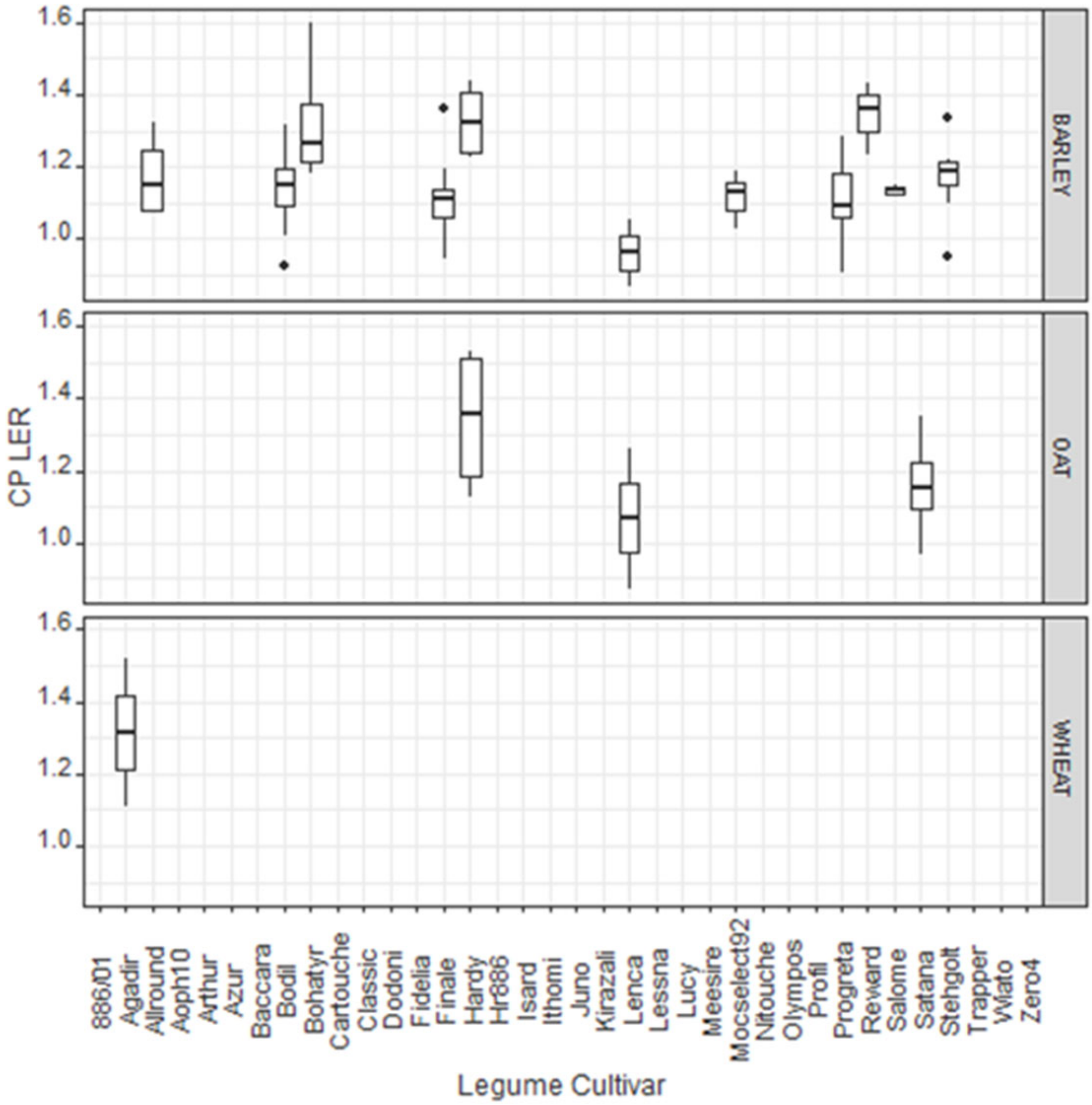

Fig. 2. Boxplots summarising the CPLER of the intercrops for barley, oat and wheat by legume variety.

Eighteen of the pea varieties have been paired with barley, 14 with oats and eight with wheat. The median LER for the pea component paired with barley was always greater than 1. However, the results for oats and wheat were more variable as the LER for pea variety “Lessna” paired with oats was <1, and the performance of three of the pea varieties paired with wheat was worse than the sole crop. There were fewer records for CPLER (Fig. 2). Nevertheless, with the exception of “Lenca” paired with barley, the CPLERs were greater than 1. There were 16, 10 and six varieties of barley, oats and wheat respectively grown with peas (Fig. 3). The cereal varieties showed more variability in the LERs compared to the legume varieties (Fig. 3). The results indicate that the oat variety “Effektiv” and the wheat variety “Cezanne” when paired with peas produced a lower yield than the sole crops. In the case of CP, only the barley variety “Chapais” had an LER <1 (Fig. 4).

Discussion

The main aim of this work was to assess the impact of management factors on the potential for pea/cereal intercrops to contribute to more diversified and resilient agro-ecological arable cropping systems less dependent on external inputs. The management factors examined were perhaps the

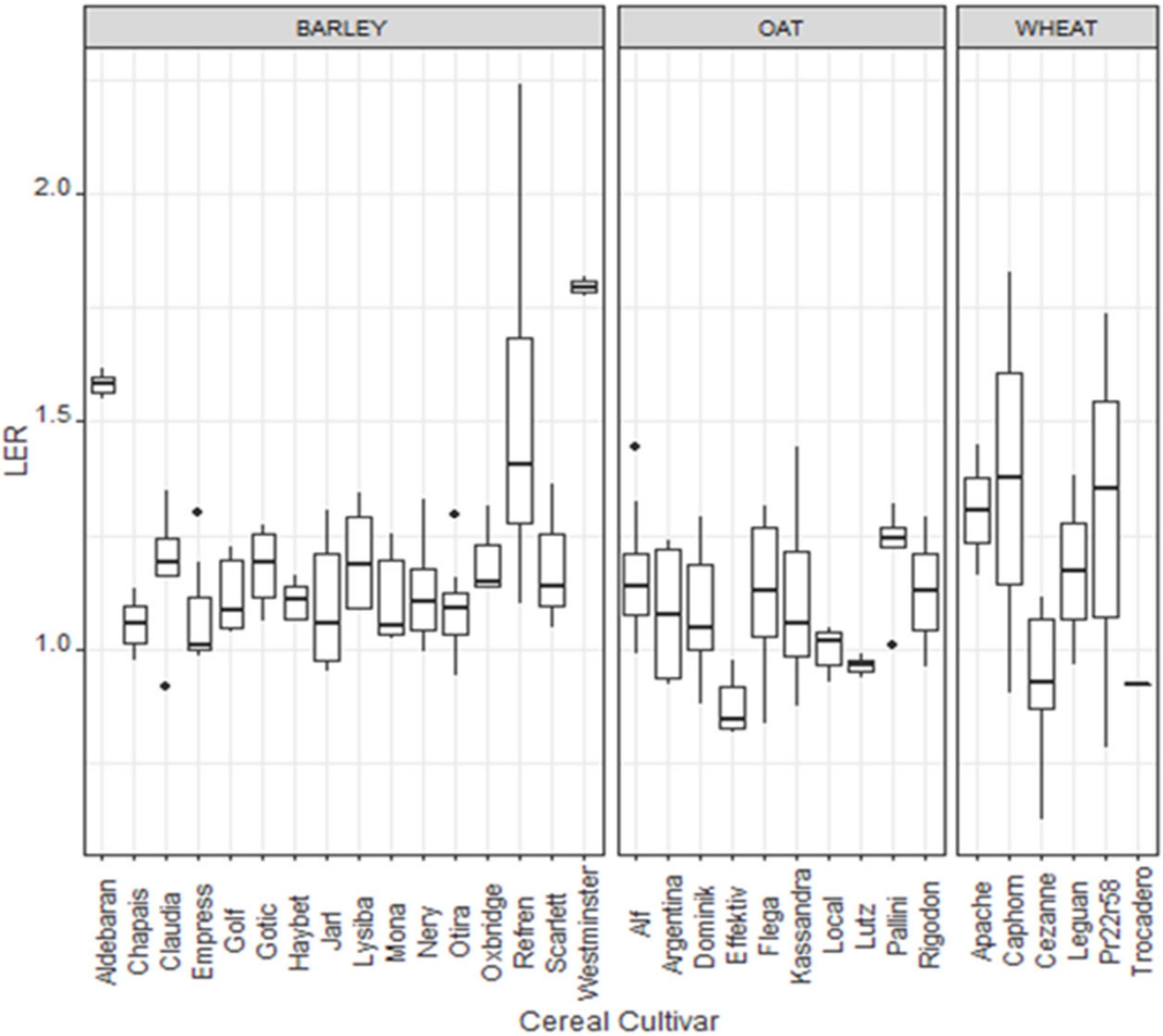

Fig. 3. Boxplots summarising the LER of the intercrops for barley, oat and wheat by cereal variety.

two most fundamental ones when cultivation of an intercrop is considered; choice of species to be grown and within that, what variety of each species. In the majority of cases the pea/cereal intercrops in this study were more productive per unit land area than their sole crops, thus meeting the objective of a more diversified system with reduced inputs. Across the different varieties of both peas and cereals there was a considerable range of LER values with just a few varieties of each showing values considerably above the median. This demonstrates the potential for further production increases and the characteristics of these varieties should be investigated to that end.

In addition to increased yield, the pea/cereal intercrops also showed increased CP production per unit land area, thus showing that intercrops have the potential to contribute to increased protein production in Europe. However, barley was the only cereal species with more than three sets of data for CP, indicating that more research is needed across the range of cereal species. Within barley there were again large effects of variety on CPLER and this variation appeared to be larger for barley variety than for pea. Thus, choice of barley variety may be the most important factor for these intercrops. The reason for this is not clear from this study, but may be related to the greater efforts made to improve nitrogen use efficiency in barley breeding programmes conducted under high-fertiliser-input conditions.

The analysis presented here has concentrated on choice of species and variety as essential management decisions. There are many other management factors that are likely to influence the performance of intercrops to a greater or lesser extent. The physical design of the system in terms of whether the two species are mixed at sowing or sown separately, sown in rows, strips or

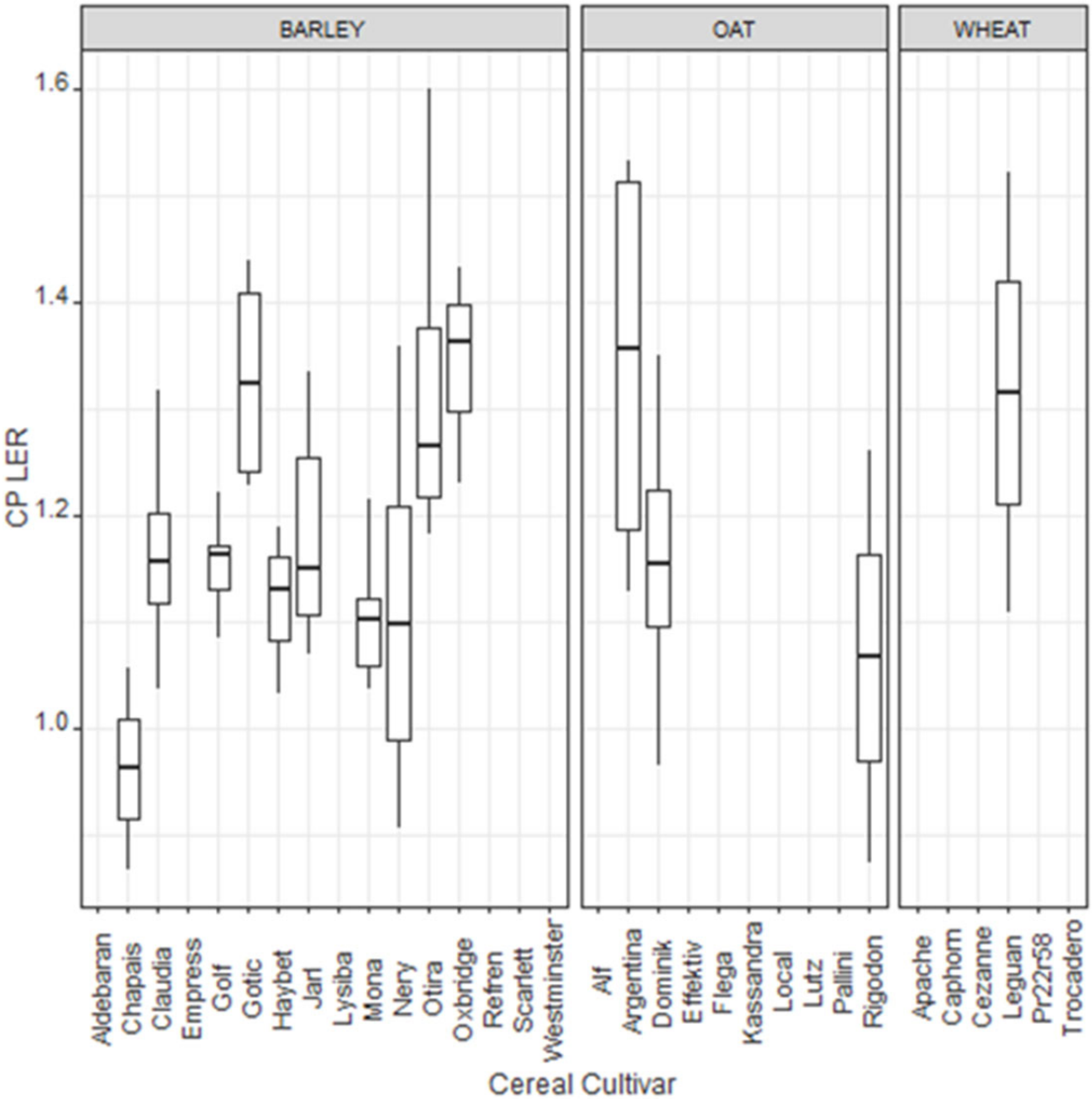

Fig. 4. Boxplots summarising the CPLER of the intercrops for barley, oat and wheat by cereal variety.

broadcast, and row spacing are all likely to be important considerations in a system so dependent on the physical interaction of the species. More conventional agricultural management factors are also likely to have an effect, such as the choice of sowing and harvesting dates, use of any fertilisers and crucially the choice of market for the harvested products.

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References

Barillot R, Combes D, Pineau S, Huynh P, Escobar-Gutierrez A J. 2014. Comparison of the morphogenesis of three genotypes of pea (*Pisum sativum*) grown in pure stands and wheat-based intercrops. *AoB Plants,* pp. 2041–2851.

Baxevanos D, Tsialtas I T, Vlachostergios D N, Hadjigeorgiou I, Dordas C, Lithourgidis A. 2017. Cultivar competitiveness in pea-oat intercrops under Mediterranean conditions. *Field Crops Research* **214**:94–103.
Bedoussac L, Justes E. 2011. A comparison of commonly used indices for evaluating facilitation, complementarity and competition within intercropped species in durum wheat-winter pea intercrops. *Field Crops Research* **124**:25–36.
Bedoussac L, Journet E-P, Hauggaard-Nielsen H, Naudin C, Corre-Hellou G, Jensen E S, Prieur L, Justes E. 2015. Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. *Agronomy for Sustainable Development* **35**:911–935.
Chapagain T, Riseman A. 2014. Barley-pea intercropping: Effects on land productivity, carbon and nitrogen transformations. *Field Crops Research* **166**:18–25.
Chen C C, Westcott M, Neill K, Wichman D, Knox M. 2004. Row configuration and nitrogen application for barley-pea intercropping in Montana. *Agronomy Journal* **96**:1730–1738.
Corre-Hellou G, Fustec J, Crozat Y. 2006. Interspecific competition for soil N and its interaction with N-2 fixation, leaf expansion and crop growth in pea-barley intercrops. *Plant and Soil* **282**:195–208.
Craig C. 2018. *The Farm Management Handbook 2018/19*. Edinburgh, UK: SAC Consulting.
Dordas C A, Vlachostergios D N, Lithourgidis A S. 2012. Growth dynamics and agronomic-economic benefits of pea-oat and pea-barley intercrops. *Crop and Pasture Science* **63**:45–52.
Ghaley B B, Hauggaard-Nielsen H, Hogh-Jensen H, Jensen E S. 2005. Intercropping of wheat and pea as influenced by nitrogen fertilization. *Nutrient Cycling in Agroecosystems* **73**:201–212.
Gilliland T J, Johnston J. 1992. Barley pea mixtures as cover crops for grass re-seeds. *Grass and Forage Science* **47**:1–7.
Gronle A, Lux G, Boehm H, Schmidtke K, Wild M, Demmel M, Brhuber R, Wilbois K-P, Hess J. 2015. Effect of ploughing depth and mechanical soil loading on soil physical properties, weed infestation, yield performance and grain quality in sole and intercrops of pea and oat in organic farming. *Soil and Tillage Research* **148**:59–73.
Hauggaard-Nielsen H, Jensen E S. 2001. Evaluating pea and barley cultivars for complementarity in intercropping at different levels of soil N availability. *Field Crops Research* **72**:185–196.
Hauggaard-Nielsen H, Andersen M K, Jornsgaard B, Jensen E S. 2006. Density and relative frequency effects on competitive interactions and resource use in pea-barley intercrops. *Field Crops Research* **95**:256–267.
Hauggaard-Nielsen H, Gooding M, Ambus P, Corre-Hellou G, Crozat Y, Dahlmann C, Dibet A, von Fragstein P, Pristeri A, Monti M, Jensen E S. 2009. Pea–barley intercropping for efficient symbiotic N2-fixation, soil N acquisition and use of other nutrients in European organic cropping systems. *Field Crops Research* **113**:64–71.
Hauggaard-Nielsen H, Jornsgaard B, Kinane J, Jensen E S. 2008. Grain legume-cereal intercropping: The practical application of diversity, competition and facilitation in arable and organic cropping systems. *Renewable Agriculture and Food Systems* **23**:3–12.
Izaurralde R C, Juma N G, Mcgill W B. 1990. Plant and nitrogen yield of barley-field pea intercrop in cryoboreal-subhumid central Alberta. *Agronomy Journal* **82**:295–301.
Jannoura R, Joergensen R G, Bruns C. 2014. Organic fertilizer effects on growth, crop yield, and soil microbial biomass indices in sole and intercropped peas and oats under organic farming conditions. *European Journal of Agronomy* **52**:259–270.
Jensen E S. 1996. Grain yield, symbiotic N-2 fixation and interspecific competition for inorganic N in pea-barley intercrops. *Plant and Soil* **182**:25–38.
Kwabiah A B, Spaner D, Todd A G. 2005. Shoot-to-root ratios and root biomass of cool-season feed crops in a boreal Podzolic soil in Newfoundland. *Canadian Journal of Soil Science* **85**:369–376.
Kontturi M, Laine A, Niskanen M, Hurme T, Hyovela M, Peltonen-Sainio P. 2011. Pea-oat intercrops to sustain lodging resistance and yield formation in northern European conditions. *Acta Agriculturae Scandinavica Section B-Soil and Plant Science* **61**:612–621.

Lauk R, Lauk E. 2008. Pea-oat intercrops are superior to pea-wheat and pea-barley intercrops. *Acta Agriculturae Scandinavica Section B-Soil and Plant Science* **58**:139–144.
Li C, Hoffland E, Kuyper TW, Yu Y, Zhang C, Li H, Zhang F, van der Werf W. 2020. Syndromes of production in intercropping impact yield gains. *Nature Plants* **6**:653–660.
Lithourgidis A S, Vlachostergios D N, Dordas C A, Damalas C A. 2011. Dry matter yield, nitrogen content, and competition in pea-cereal intercropping systems. *European Journal of Agronomy* **34**:287–294.
Mason W K, Pritchard K E. 1987. Intercropping in a temperate environment for irrigated fodder production. *Field Crops Research* **16**:243–253.
Monti M, Pellicano A, Santonoceto C, Preiti G, Pristeri A. 2016. Yield components and nitrogen use in cereal-pea intercrops in Mediterranean environment. *Field Crops Research* **196**:379–388.
Musa M, Leitch M H, Iqbal M, Sahi F U H. 2010. Spatial arrangement affects growth characteristics of barley-pea intercrops. *International Journal of Agriculture and Biology* **12**:685–690.
Neugschwandtner Reinhard W, Kaul Hans-Peter. 2014. Sowing ratio and N fertilization affect yield and yield components of oat and pea in intercrops. *Field Crops Research* **155**:159–163.
Neumann A, Schmidtke K, Rauber R. 2007. Effects of crop density and tillage system on grain yield and N uptake from soil and atmosphere of sole and intercropped pea and oat. *Field Crops Research* **100**:285–293.
Ogórek R, Lejman A, Sobkowicz P. 2019. Effect of the intensity of weed harrowing with spike-tooth harrow in barley-pea mixture on yield and mycobiota of harvested grains. *Agronomy* **9**(2):103
Pappa V A, Rees R M, Walker R L, Baddeley J A, Watson C A. 2012. Legumes intercropped with spring barley contribute to increased biomass production and carry-over effects. *Journal of Agricultural Science* **150**:584–594.
Pelzer E, Bazot M, Makowski D, Corre-Hellou G, Naudin C, Al Rifai M, Baranger E, Bedoussac L, Biarnes V, Boucheny P, Carrouee B, Dorvillez D, Foissy D, Gaillard B, Guichard L, Mansard M-C, Omon B, Prieur L, Yvergniaux M, Justes E, Jeuffroy M-H. 2012. Pea-wheat intercrops in low-input conditions combine high economic performances and low environmental impacts. *European Journal of Agronomy* **40**:39–53.
Pelzer E, Hombert N, Jeuffroy M-H, Makowski D. 2014. Meta-analysis of the effect of nitrogen fertilization on annual cereal-legume intercrop production. *Agronomy Journal* **106**:1775–1786.
Pelzer E, Bazot M, Guichard L, Jeuffroy M-H. 2016. Crop management affects the performance of a winter pea-wheat intercrop. *Agronomy Journal* **108**:1089–1100.
Podgorska-Lesiak M, Sobkowicz P. 2013. Prevention of pea lodging by intercropping barley with peas at different nitrogen fertilization levels. *Field Crops Research* **149**:95–104.
Pötzsch F, Lux G, Lewandowska S, Bellingrath-kimura S D. 2019. Optimizing relative seed frequency of intercropped pea and spring barley. *European Journal of Agronomy* **105**:32–40.
R Core Team. 2008. *R: A Language and Environment for Statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.
Rauber R, Schmidtke K, Kimpel-Freund H. 2001. The performance of pea (*Pisum sativum* L.) and its role in determining yield advantages in mixed stands of pea and oat (*Avena sativa* L.). *Journal of Agronomy and Crop Science* **187**:137–144.
Robinson R G. 1960. Oat-pea or oat-vetch mixtures for forage or seed. *Agronomy Journal* **52**:546–549.
Salawu M B, Adesogan A T, Weston C N, Williams S P. 2001. Dry matter yield and nutritive value of pea/wheat bi-crops differing in maturity at harvest, pea to wheat ratio and pea variety. *Animal Feed Science and Technology* **94**:77–87.
Strydhorst S M, King J R, Lopetinsky K J, Harker K N. 2008. Forage potential of intercropping barley with faba bean, lupin, or field pea. *Agronomy Journal* **100**:182–190.
Tsialtasa J T, Baxevanos D, Vlachostergios D N, Dordas C, Lithourgidis A. 2018. Cultivar complementarity for symbiotic nitrogen fixation and water use efficiency in pea-oat intercrops and its effect on forage yield and quality. *Field Crops Research* **226**:28–37.

Tortorella D, Scalise A, Pristeri A, Petrovicova B, Monti M, Gelsomino A. 2013. Chemical and biological responses in a Mediterranean sandy clay loam soil under grain legume-barley intercropping. *Agrochimica* **57**:1–21.

Uzun Aysen, Asik F F. 2012. The effect of mixture rates and cutting stages on some yield and quality characters of pea (*Pisum sativum* L.) plus oat (*Avena sativa* L.) mixtures. *Turkish Journal of Field Crops* **17**:62–66.

Wickham H. 2016. *ggplot2: Elegant Graphics for Data Analysis*. New York, USA: Springer-Verlag New York, https://ggplot2.tidyverse.org}.

Voisin A S, Guéguen J, Huyghe C, Jeuffroy M-H, Magrini M-B, Meynard J-M, Mougel C, Pellerin S, Pelzer E. 2014. Legumes for feed, food, biomaterials and bioenergy in Europe: a review. *Agronomy for Sustainable Development* **34**:361–380.

Yu Y, Stomph T J, Makowski D, Zhang L Z, van der Werf W. 2016. A meta-analysis of relative crop yields in cereal/legume mixtures suggests options for management. *Field Crops Research* **198**:269–279.