European Journal of Agronomy 91 (2017) 25–33

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

Research paper

Does intercropping enhance yield stability in arable crop production? A meta-analysis

Md. Raseduzzaman, Erik Steen Jensen*

Department of Biosystems and Technology, Swedish University of Agricultural Sciences, 23053 Alnarp, Sweden

ARTICLE INFO

Keywords:
Intercropping
Yield stability
Intercropping design
Meta-analysis
Food security
Climate change

ABSTRACT

The adverse effects of climate change are significantly decreasing yield levels and yield stability over time in current monocropping systems. Intercropping (IC), *i.e.* growing more than one species simultaneously in the same field, often increases resource use efficiency and agricultural productivity compared with growing the component crops solely and can enhance yield stability. This meta-analysis of published IC literature quantified and analysed yield stability in IC compared with the respective sole crops, focusing on the effect of intercrop components (*e.g.* cereal-grain legume, non-cereal-grain legume), experimental patterns (*e.g.* experiment over years, experiment over locations), IC design (*e.g.* additive and replacement) and climatic zone (*e.g.* tropical, subtropical, and temperate). In total, 33 articles were analysed. The coefficient of variation (%CV) of yields was used for assessing yield stability, with lower CV value indicating higher yield stability. The analysis showed that cereal-grain legume IC (CV = 22.1) significantly increased yield stability compared with the respective grain legume sole crops (CV = 31.7). Moreover, compared with the respective cereal and legume sole crops, IC in the cereal-grain legume systems gave higher yield stability than IC in the non-cereal-grain legume systems. Compared with the respective cereal (CV = 25.3) and legume (CV = 30.3) sole crops, IC (CV = 19.1) in a replacement design had significantly ($P < 0.05$) higher yield stability. Also intercropping in replacement design gave more stable yields than IC in an additive design. In tropical regions, cereal sole crops (CV = 26.3) showed lower yield stability than IC (CV = 17.7) and legume sole crops (CV = 21.7). However, IC in all climatic zones showed higher yield stability than both sole crops. Moreover in our analysis, it was found that a higher yield level provided higher yield stability in crop production. Thus, increasing crop diversification through IC of cereals and grain legumes can enhance yield stability and food security, making an important contribution to eco-functional, ecological or sustainable intensification of global food production.

1. Introduction

Agriculture has to address simultaneously several intertwined challenges, including ensuring food security for an increasing global population through increased productivity and income, reducing the environmental impact of agriculture and increasing climate change adaptation and mitigation (Beddington et al., 2012; Foresight, 2011; FAO, 2011; IAASTD, 2009). It is predicted that by 2050, more than 2 billion people will be suffering from food insecurity (Bruinsma, 2009; World Bank, 2007). One important reason for food insecurity in the developing countries is yield instability in the current monoculture cropping system, due to its lower resilience to environmental perturbations and biotic stresses (Lithourgidis et al., 2011). Yield stability is crucial for the food security of subsistence and small-scale farmers (Trenbath, 1999).

These future challenges require food systems to become more efficient and resilient at all scales, from farm to global level. Diversification of cropping systems in time and space is expected to be important in this context (IPES-Food, 2016; IAASTD, 2009). Intercropping, *i.e.* growing two or more crops species simultaneously in the same field (Vandermeer et al., 1998), is a cultivation practice that can contribute to eco-functional, ecological and sustainable intensification in crop production (IPES-Food, 2016; Jensen et al., 2015; Bommarco et al., 2013; IAASTD, 2009; Niggli et al., 2008). It is considered an efficient way to achieve sustainability in agriculture by many farmers, researchers and policy makers world-wide (Vandermeer, 2011; Jackson et al., 2007; Altieri, 1999).

Intercropping brings advantages based on the ecological principles of competition, complementarity and compensation (Hauggaard-Nielsen et al., 2008; Vandermeer et al., 1998). The most common advantage of intercropping is production of higher yield in a specific area by more efficient and complementary use of available growth resources

* Corresponding author.
E-mail addresses: rashed.bau87@gmail.com (Md. Raseduzzaman), erik.steen.jensen@slu.se (E.S. Jensen).

http://dx.doi.org/10.1016/j.eja.2017.09.009
Received 9 April 2017; Received in revised form 6 September 2017; Accepted 20 September 2017
1161-0301/

compared with the sole crops (Hauggaard-Nielsen et al., 2008; Dhima et al., 2007; Banik et al., 2006 Jensen, 1996). Intercropping of legumes, which can biologically fix their own nitrogen (N) from atmospheric N_2 (di-nitrogen), with cereals is one way to enhance complementarity in nitrogen resource use (Andersen et al., 2005 Jensen, 1996). Due to the lower competitive ability of grain legumes for soil N acquisition, since they can fix the N_2 they require, intercropped cereals can obtain a greater proportion of soil N, leading to a yield increase over sole crops (Hauggaard-Nielsen and Jensen 2005; Corre-Hellou et al., 2006). Moreover, intercropping brings a planned diversity of species into the cropping system, which is considered to make the system more resilient to environmental perturbations, pests and diseases, thus enhancing food security (Frison et al., 2011).

The yield-stabilising effect of intercropping is believed to be based on the compensation principle, *i.e.* two different crops are less likely to be both lost due to *e.g.* disease, pest or extreme weather. It has been demonstrated that, at any given disaster level, intercropping has a much lower probability of failure than either sole crop (Rao and Willey, 1980). If one species in the intercrop is affected by disease, the other may compensate by using the available resources, stabilising the overall yield. Complementarity in resource niches, such as different rooting depth, differential canopy architecture or differential resource use (as with nitrogen), are other factors contributing to greater yield stability. Moreover, one intercrop component may alter the micro-climate of another component, which may be unfavourable for pest and disease attack, resulting in greater productivity and stability.

Intercropping is also more resilient to abiotic factors, which is likely to enhance yield stability in crop production. For example, after Hurricane Mitch it was observed that in Central American hillsides, farmers following intercropping suffered less damage than their neighbours followed sole crop practices (Altieri et al., 2012). After Hurricane Ike hit Cuba in 2008, one field survey estimated that the losses were only 50% in intercropped fields, compared with 90–100% in sole crop fields (Rosset et al., 2011).

At present, intercropping is more common in cropping systems in developing countries, perhaps because it is assumed to give more stable yield than sole crops (Sileshi et al., 2012; Dapaah et al., 2003; Horwith, 1985). A number of field experiments have analysed the yield stability in intercropping, but their results are sometimes conflicting (Luo et al., 2016; Dapaah et al., 2003; Blade et al., 1991; Faris et al., 1983). Recently, a few meta-analysis have compared intercropping with sole cropping, mainly focusing on management factors, intercrop productivity, resource use efficiency *etc*. (Yu et al., 2016; Yu et al., 2015; Pelzer et al., 2014). However, no quantitative synthesis seems to have been made on the effect of intercropping on yield stability and the likely causes of variability in yield. The aim of this study was thus to analyse and synthesise experimental evidence on the effects of intercropping of arable crops on grain yield stability compared with that of the respective sole crops, through a meta-analysis of published data.

2. Materials and methods

2.1. Data collection from published articles

An extensive search of peer-reviewed literature was conducted in Web of Science™ databases on 5 January 2016 and in Scopus on 11 January 2016. The initial search term was 'intercrop' OR 'mixed crop' OR 'mixed cultivation' OR 'crop mixture' in the title, for papers published between 1980 and 2016, and then the yielded literatures were subsequently refined by search term 'Grain yield'. The search yielded 2513 publications in Web of Science™ and 586 publications in Scopus. An additional literature search was conducted in Google Scholar using the search term 'intercrop' OR 'mixed crop' AND 'grain yield' in the 'anywhere in the article' option, sorted by relevance to get more relevant articles at the beginning. The first 1000 articles in Google Scholar search were considered for further action, assuming that the more relevant articles would be among these. All 4099 publications (2513 in Web of Science™, 586 in Scopus and 1000 in Google Scholar) found were screened carefully according to the selection criteria to achieve the maximum number of articles for the analysis. This is because if the selection criteria are not carefully considered, they may exclude compelling studies or, alternatively, include comprehensive sets of studies that only tangentially address the hypothesis (Lortie and Callaway, 2005).

Our initial selection criterion was whether the experiment was conducted for a minimum of three years (temporal variability) or at a minimum of three locations (spatial variability) or for at least two years at two locations. For a particular experiment, all locations had to be situated within the same country. Conducting a particular experiment in different agro-climatic zones or countries may result in large yield differences, which is not expected for this analysis, since in reality farmers grow their crops in the same location or in different locations within the same country. For this criterion, we considered the information available in abstract and materials & methods. If the initial selection criterion was fulfilled, we then took the results section into account for the rest of the selection criteria. Articles ideally had to have grain yield data for each experimental year and location. Articles presenting the mean value of grain yield for different years or locations, instead of mentioning yield data for all experimental years or locations, were not considered in the meta-analysis, unless the mean values were presented together with the standard deviation (SD) or coefficient of variation (CV) for grain yield. This was because without yield data for all years or locations, it is not possible to calculate SD as well as CV. Experiments containing different cultivars of the same species at different locations or years were also excluded from the analysis, because different cultivars have differing yield performance. The experiments had to have sole crop treatments for both intercrop component species, to allow yield stability between sole crops and intercrops to be compared. If a publication was found in different databases or if duplicate datasets were reported in different publications, they were included only once.

A total of 33 articles (articles 1–33 in Table 1) were selected based on the selection criteria. However, during data extraction, besides these 33 articles, we got four more articles (articles 34–37 in Table 1) which only reported the cereal sole crop and cereal-grain legume intercrop data. No legume sole crop yield data were reported in these four articles. Those datasets were also extracted and analysed separately.

These selected articles covered a wide range of agroecological and pedo-climatic conditions. Cereal-grain legume intercropping experiments were described for all climatic conditions, but data on cereal-cereal (*e.g.* wheat-maize) intercrops were only available for China. A large proportion (76%) of the studies were carried out at research stations, while the remainder were carried out in farmers' fields. Most of the experiments (85%) were laid out as a randomised complete block design and the remainder as a split-plot design.

Publication bias is well known in meta-analysis (Koricheva et al., 2013). The bias occurs when the published studies tend to report larger or more significant effect sizes (*e.g.* effect of a treatment). However, we assumed that if any publication bias was present, it had no impact on the results of this meta-analysis due to different aims for use of the yield data. Almost all IC articles reviewed used grain yield data to compare the effectiveness of the treatments and to compare the yield performance between sole crops and intercrops. But in this study, the grain yield data were used to measure coefficient of variation (CV) in order to analyse yield stability.

2.2. Response variable

The coefficient of variation in percent (%CV) was used as the response variable in the analysis. Coefficient of variation is widely used to quantify and compare the year-to-year yield stability or variability of crops, with a higher CV value indicating higher yield variability *i.e.*