Ecosystem services in cassava intercropping: a global synthetic review

Erik Delaquis[1,3]*, Stef de Haan[2,3], Kris A.G. Wyckhuys[4]

[1] International Center for Tropical Agriculture (CIAT), Vientiane, Lao PDR; [2] International Center for Tropical Agriculture (CIAT), Hanoi, Vietnam; [3] CGIAR Research Program on Roots, Tubers, and Bananas; [4] Chrysalis, Hanoi, Vietnam

Introduction

Intensification and extensification of agriculture are eroding the integrity of tropical ecosystems. As global land comes under increasing anthropogenic management, considering the impacts of management practices on ecosystem services (ES) is essential.

Cassava (*Manihot esculenta* Crantz) cultivation has expanded dramatically in the tropics, currently representing over 25 million hectares managed by millions of smallholders (Fig. 1). Diversification is often cited as a strategy for augmenting the functioning of ES in agricultural landscapes (Brooker et al., 2015; Kremen & Miles, 2012). Despite this, attempts to comprehensively evaluate diversification practices in cassava from an ES perspective remain rare.

We conducted a systematic literature review of intercropping in cassava cultivation systems, and employed the concept of ES bundles to evaluate the impacts of diversification on a key set of ES.

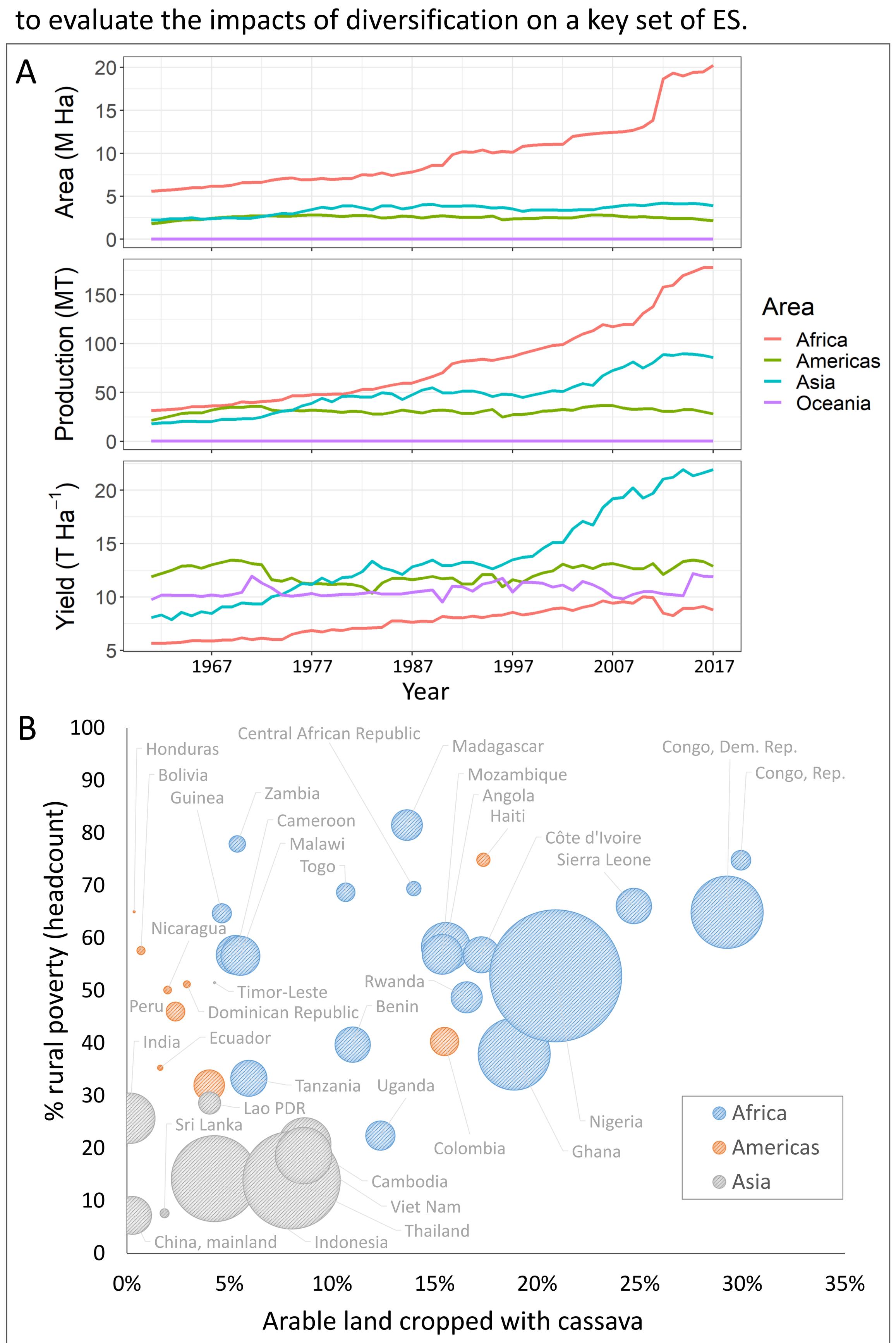

Figure 1. Panel A displays regional cassava area, yield, and production from 1961-2017; panel B shows major cassava producing countries in 2015, ordered by dedication of arable land under cassava cultivation and rural poverty rates (by national definition), with bubble size representing relative domestic cassava production (FAOSTAT, 2016; World Bank, 2016).

Literature review and analysis

A global literature search was conducted (July 2015, Web of Science) using the terms 'cassava' OR '*Manihot esculenta*' AND 'intercrop' OR 'polyculture'. Studies were selected requiring a) cassava was a focal crop, b) intercropping was both spatial and temporal, and c) publication was in peer-reviewed journals or detailed reports of research centers. A total of 189 references were returned, with 170 investigating intercropping and providing original experimental results for one or more ES variables. Publications dated from 1975-2015, represented 27 countries, and evaluated 330 instances of intercropping. Research predominantly focused on provisioning and regulating services (125 and 168 studies, respectively). Yield and land use productivity were the most commonly evaluated (110 and 45 studies, respectively), with other examples including pest and disease dynamics (38 instances) and nutrient cycling (29 instances).

For analysis of results a subset of studies was selected which included a) appropriate cassava monoculture controls, b) robust methods and description of data, c) land productivity expressed as land equivalent ratio (LER) or area-time equivalent ratio (ATER), soil services, water services, and pest or disease regulation. A total of 95 studies from a range of agroecological contexts met the above criteria (Fig. 2)

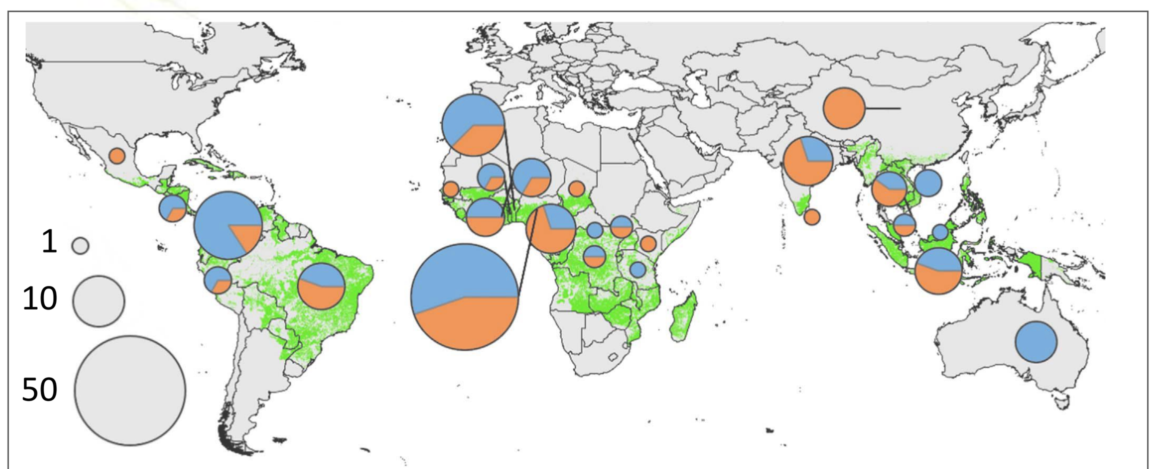

Figure 2. Global distribution of cassava (green background) and intercropping studies identified in the literature analysis. Blue segments indicate studies which met all criteria for inclusion in detailed ecosystem service analysis, while orange segments were excluded.

Cassava intercropping

To evaluate the magnitude and direction of effects on ES, selected studies were aggregated by service type and data plotted to visualize the means and ranges of experimental findings. LER is a common measure for comparing the yield of all crops in an intercropping system with that of a monoculture in the same area. We aggregated LER results by intercrop species.

Indicators of pest pressure (eg. pest numbers, crop damage ratings, etc.) were compiled and ordered by pest type and species. To achieve a comparable measure to LER, these were converted to percentages of the results from the respective cassava monoculture controls in each study. Water, soil, and disease measures were also aggregated in a similar manner (results not shown; see Delaquis et al., 2018).

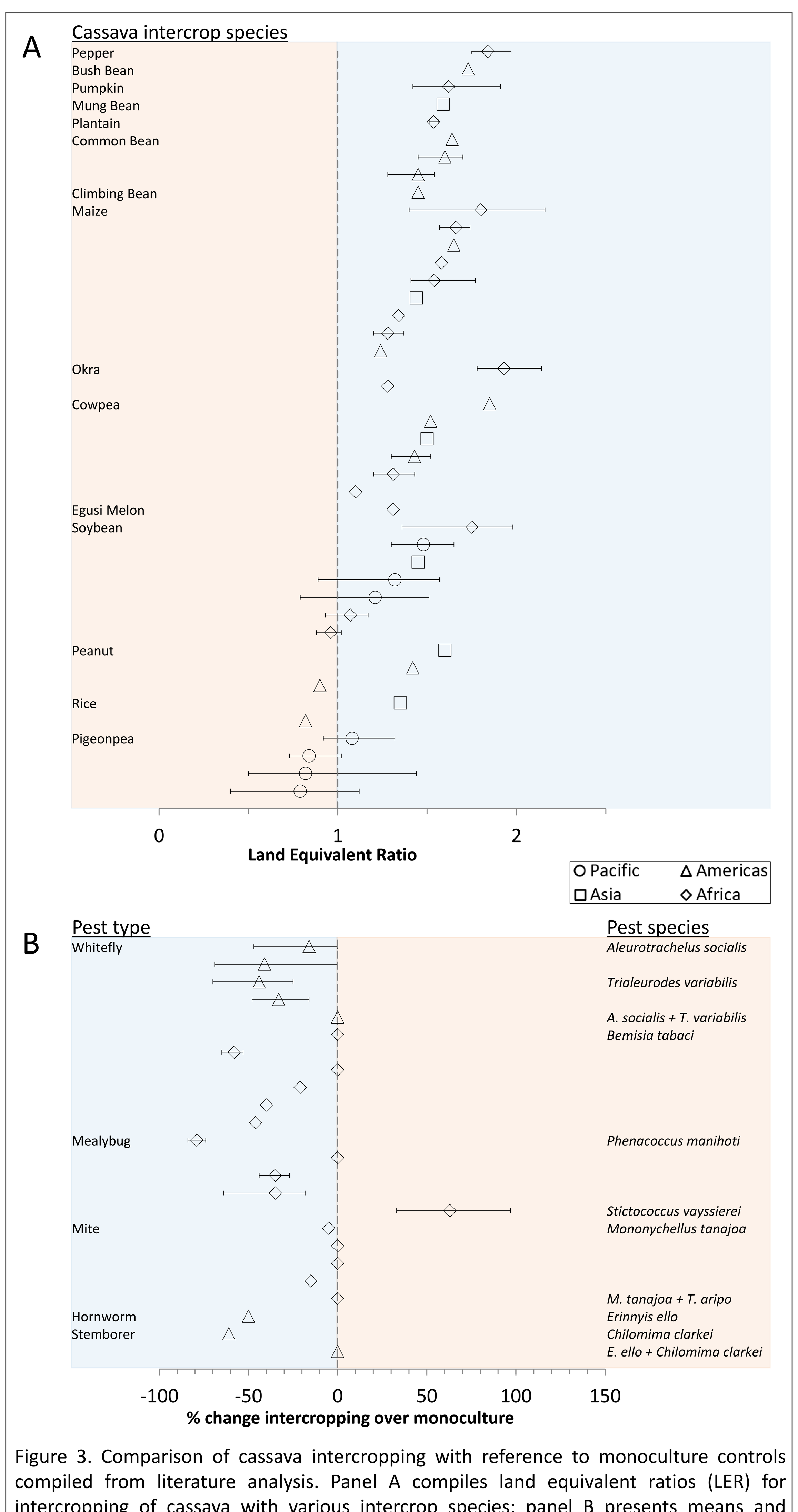

Figure 3. Comparison of cassava intercropping with reference to monoculture controls compiled from literature analysis. Panel A compiles land equivalent ratios (LER) for intercropping of cassava with various intercrop species; panel B presents means and ranges of arthropod pest indicators relative to their respective monoculture controls. In both panels horizontal bars represent ranges in cases where intercrops were kept constant, but another variable was changed (eg. varieties, fertilizer application rates). Full reference and indicator lists provided in Delaquis et al. (2018).

Ecosystem service bundles

To visualize ES bundles, we aggregated data in four major crop types and employed a vote-counting approach to gain a composite measure of intercropping-related outcomes across all five evaluated categories (Fig. 4). Results are binned into four qualitative categories based on whether the outcome is considered a 'benefit', 'disbenefit', 'mixed', or no effect (no statistically significant differences detected). We selected the top 4 most commonly-studied grain legumes as a distinct crop group since they made up a large proportion of the arrangements.

Our findings demonstrate that ES bundles are sustained by a diverse range of companion crops in diverse cassava systems, with 25 positive impacts vs. 3 negative ones for maize (total n = 43), 5 vs. 1 for other Poaceae (total n =10), 23 vs. 3 for four species of grain legumes (total n =40), and 9 vs. 0 for trees (total n = 24), respectively.

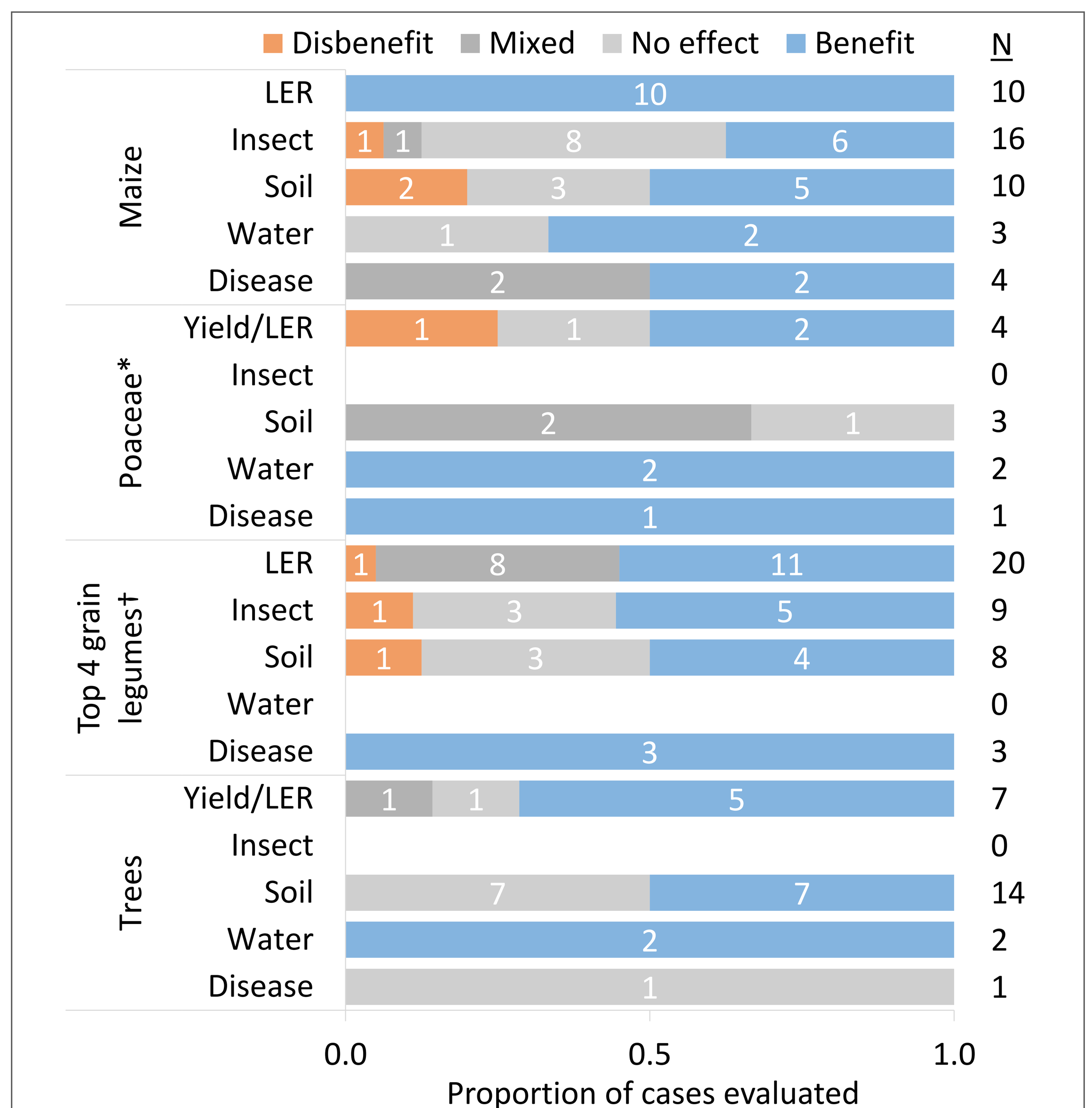

Fig. 4. Vote-count of study findings for key ecosystem services with major cassava intercrop species. Numbers on bars indicate number of studies, N= total studies evaluated for each trait/crop combination. *Poaceae excluding maize, †Soybean, peanut, cowpea, and pigeonpea.

Biases, gaps, and future work

Despite the 189 results returned by this review, there is still a critical lack of research and/or quality data for many ES x species x agroecological contexts. To date research has largely focused on confirmation of effects for arrangements which were presumed *a priori* to be beneficial (eg. legume intercrops increasing soil N), and rarely taking a more holistic evaluation of ES impacts.

The phenomenon of publication bias, in which 'successful' experiments are more likely to be submitted or published, has been well documented (Dickersin, 1990). This is particularly relevant to intercropping studies which seek to identify overyielding. Focus on overyielding was evident in the literature, often to the detriment of analysis of other ES.

Vote-counting is a coarse first method for the evaluation of complex outcomes. Meta analytical approaches hold promise for future detailed analysis of effect sizes in intercropping studies, although hurdles remain relating to data quality and methodological consistency.

Key Conclusions

- Intercropping supports a wide range of ecosystem services across diverse cassava-based production systems worldwide
- Future research should pursue a more holistic evaluation of ecosystem services in intercropping to evaluate tradeoffs between services
- Although yield and LER remain important metrics, cassava production systems should consider other ecosystem service ramifications in an increasingly widely grown crop, often produced in endangered tropical agroecosystems

References:

Brooker, R.W., Bennett, A.E., Cong, W.F., et al., 2015. Improving intercropping: a synthesis of research in agronomy, plant physiology and ecology. New Phytol. 206, 107–117.

Delaquis E, de Haan S, Wyckhuys KAG. 2018. On-farm diversity offsets environmental pressures in tropical agroecosystems: A synthetic review for cassava-based systems. Agriculture, Ecosystems and environment, 251:226-235.

Dickersin, K., 1990. The existence of publication bias and risk factors for its occurrence. J. Amer. Med. Assoc. 263 (10), 1385–1389.

Kremen, C., Miles, A., 2012. Ecosystem services in biologically diversified versus conventional farming systems: benefits, externalities, and trade-offs. Ecol. Soc. 17, 40.