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META-ANALYSIS

# Yield and labor relations of sustainable intensification options for smallholder farmers in sub-Saharan Africa. A meta-analysis

A. Sigrun Dahlin[1] · Leonard Rusinamhodzi[2]

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## Abstract

Sustainable intensification of agricultural production is needed to ensure increased productivity relative to inputs. Short-term yield returns and labor input are major determinants of the fate of sustainable intensification options on smallholder farms in sub-Saharan Africa because labor shortage is often acute, and most farmers lack access to labor-saving technologies. We assessed the relationship between maize grain yield change and labor input from a total of 28 published papers (631 data pairs) including subsets of data pairs within specific sustainable intensification practices. Among the reviewed technologies, manually dug planting basins showed ratios between the change in yield and change in labor inputs ($\Delta Y/\Delta L$) below 1, suggesting that labor demand increased more than yield. In contrast, ridging showed average $\Delta Y/\Delta L$ values $\geq 2$. No-till showed high $\Delta Y/\Delta L$ (average $\geq 1.7$) when combined with herbicides but average $\Delta Y/\Delta L \leq 1$ (total labor) when manually weeded. Manually weeded rotations showed average $\Delta Y/\Delta L \geq 1$ and manually weeded intercropping systems average $\Delta Y/\Delta L$ around 1. The relations revealed four scenarios: high yield returns but low labor demand, high yield returns and labor demand, low yield returns and labor demand, and low yield returns but high labor demand. High yield with high labor demand requires mostly investments in machinery and/or herbicides to reduce labor input. Low yield with low labor demand requires improved crop management, whereas low yield with high labor demand requires a combination of improved crop management and investments to reduce labor. This is the first comprehensive assessment showing that the sustainable intensification options being considered for smallholder farmers may increase crop yield but also labor demand. Options that include mechanization and herbicides at low cost are likely to be adopted due to their reduction effect on drudgery and total labor input.

**Keywords** Maize productivity · Labor input · Rain-fed conditions · Smallholder farmers · Soil fertility · Weed management

## 1 Introduction

The smallholder farming systems in sub-Saharan Africa (SSA) face many barriers to increased crop productivity such as low nutrient inputs, insufficient control of weeds, pests and diseases, and inadequate labor, and are generally referred to as low-input systems (e.g., Sheahan and Barrett 2017). Under the low-input systems, labor is often the major input and its availability is critical for timing operations during the production cycle; for example, labor shortage often leads to late planting whereby crops cannot take full advantage of the rains and to poor weed control leading to high competition for nutrients, water, and light, which leads to low yields (Giller et al. 2006) (Fig. 1).

Proposed technologies for sustainable intensification (SI) of crop production are often labor demanding, especially in the initial years of adoption. Labor shortages are frequent in small-holder agriculture in SSA and often aggravated by ill-health in diseases such as malaria and HIV/AIDS (Chapoto and Jayne 2008; Ajani and Ashagidigbi 2008) as well as by urbanization and a younger generation turning away from farming. This has hindered widespread uptake of technologies such as cut and carry green manures, moisture conservation strategies such as fanya juu, zaï, and tied ridges that entail substantial initial labor input or, e.g., increased labor needs for weed control (e.g., Nyamadzawo et al. 2013; Namara

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✉ A. Sigrun Dahlin
Sigrun.Dahlin@slu.se

[1] Department of Soil and Environment, Swedish University of Agricultural Sciences, P.O. Box 7014, SE-750 07 Uppsala, Sweden

[2] South Asia Regional Office, Agri Botany Division , NARC Research Station, Khumaltar, CIMMYT, P.O. Box 5186, Lalitpur, Kathmandu, Nepal

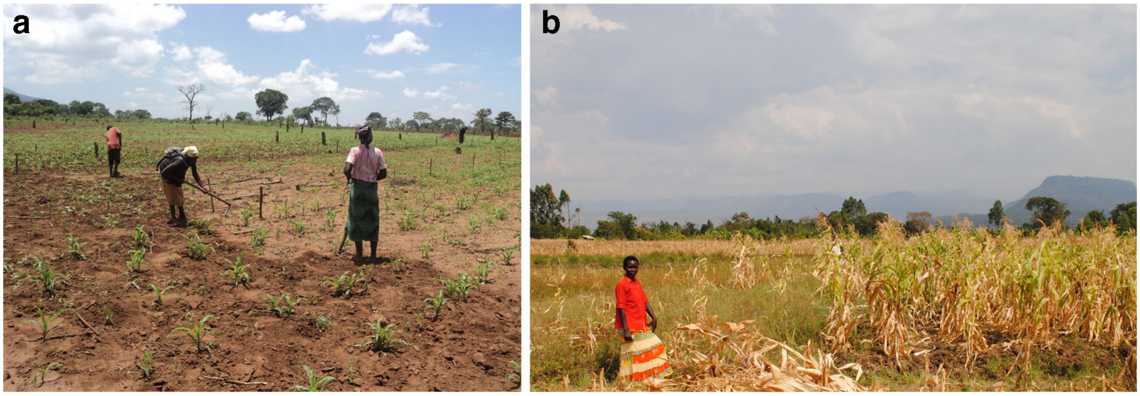


**Fig. 1** Weed management is generally one of the most labor-demanding tasks during the cropping cycle. **a** Farmers weeding by hand hoe, the most common weed control strategy on smallholder farms in SSA. **b** A farmer showing a typical field where time constraints precluded timely weeding (left) and the impact on the maize crop compared with timely weeding (right). The whole field had the same cropping history and fertilization

et al. 2003; Schuler et al. 2016; Grabowski and Kerr 2014; Gicheru 2016). Furthermore, small or no improvement in productivity may result if multiple limiting factors are addressed one at a time. Fertilizer application may, for example, increase yields marginally if weed management is delayed or carried out at low intensity (Chikoye et al. 2008; Rusinamhodzi et al. 2016), or fail to increased yields or even decrease yields by aggravating water shortage during dry spells (Rusinamhodzi et al. 2012). This may lead to abandonment and disrepute of the technologies as the investment of cash or labor does not pay off.

Smallholder farming households often have no or small economical margins and so face difficulties to invest labor and cash in improved technologies that will increase crop productivity noticeably only after several seasons. This is often so with Integrated Soil Fertility Management (ISFM)–based technologies that build soil fertility by combining organic and mineral nutrient sources (Rusinamhodzi et al. 2011; Nezomba et al. 2015) or the effects of legumes such as *Desmodium* spp. on *Striga* seed banks (Khan et al. 2008). However, benefits can be seen in one or two seasons if, for example, the technologies simultaneously address nutrient and short-term water shortages such as conservation agriculture applied in drier agro-ecological zones (Ransom 1990; Rusinamhodzi et al. 2011), or the push-pull cropping system which addresses maize stem borer, fall army worm and *Striga* while producing high-quality fodder (Vanlauwe et al. 2008; Midega et al. 2018). Intercropping with multipurpose legumes also shows promise due to the options these legumes provide at the farm level, in the short term on human and animal nutrition and in the longer term on soil fertility (Giller 2001). Intercropping systems often increase labor needs for weeding (Ransom 1989; Rusinamhodzi et al. 2012), though, and may decrease yields of, e.g., the companion cereal in the short term (Franke et al. 2017). Hence, additional strategies are needed to increase crop productivity while reducing labor input for vulnerable smallholder farmers, especially women farmers who constitute the majority (Palacios-Lopez et al. 2017). The underlying hypothesis of this study is that the short-term returns to labor are critical and may determine the fate of most promoted SI options on smallholder farms in SSA.

The objective of this study was to assess crop productivity change due to soil fertility, water, and weed management options in relation to labor demand on smallholder farms in sub-Saharan Africa through a systematic review. It is thus not intended to be another systematic review on productivity of SI options (e.g., effect of CA on yield) per se. Specifically, we sought to:

a) Assess yield change relative to labor change relative to the most commonly used technologies (baseline) for SI in different agro-ecological conditions.
b) Discuss whether the new technologies are beneficial, i.e., increase yield and reduce labor input for farmers sufficiently to warrant the risk of investment in the technologies.

## 2 Materials and methods

### 2.1 Database compilation

We retrieved a total of 28 published papers (Table 1) and 631 data pairs; 59% of these were derived from studies carried out in farmers' fields. The published papers were retrieved from online search engines such as Scopus, Google, Google Scholar, and Web of Science. Crop economic yield and the related labor input data were obtained from studies that included a baseline crop management treatment and an improved SI option under rain-fed conditions established in semi-arid and sub-humid environments with a major focus on SSA. Data had to be from studies with randomized plots and at least three

**Table 1** List of data sources, study locations, tillage and cropping systems, durations of the studies, soils, mean annual precipitation (MAP) class, and number of data pairs generated. Tillage systems: B = basins; C = conventional; NT = no-till; R = ridging. Cropping systems: I = intercrop; R = rotation; S = sole crop

| Reference | Country | Tillage systems | Cropping systems | Duration (years) | Soils | MAP class | Data pairs (*n*) |
|---|---|---|---|---|---|---|---|
| Baijukya et al. 2005 | Tanzania | C | S, R | 1 | Acrisols, Ferralsols | 600–1000, > 1000 | 6 |
| Franke et al. (2010) | Nigeria | C | I, R | 4 | Luvisols | > 1000 | 15 |
| Gathala et al. (2015) | Bangladesh | NT | S | 4 | – | > 1000 | 4 |
| Grabowski and Kerr (2014) | Mozambique | B, NT | S | 1 | – | > 1000 | 2 |
| Guto et al. (2012) | Kenya | C, NT | S | 4 | Nitisols | > 1000 | 36 |
| Jama et al. (1997) | Kenya | C | S | 1 | Kandiudalfs | > 1000 | 12 |
| Khan et al. (2008a) | Kenya | C | I | 7 | – | 600–1000, > 1000 | 29 |
| Kwiligwa et al. (1994) | Tanzania | C | S | 1 | Ferralsols | > 1000 | 8 |
| Mafongoya and Jiri (2015) | Zambia | C, NT, R | S, R | 2 | Acrisols, Luvisols | 600–1000, > 1000 | 56 |
| Mucheru-Muna et al. (2014) | Kenya | C | I | 7 | Ferralsols, Nitisols | 600–1000, > 1000 | 9 |
| Mutambara et al. (2013) | Nigeria | C | S | 1 | Luvisols | > 1000 | 1 |
| Nezomba et al. (2015) | Zimbabwe | C | S, R | 4 | Lixisols | 600–1000 | 8 |
| Ngambeki (1985) | Nigeira | NT | S | 3 | – | > 1000 | 9 |
| Ngwira et al. (2012) | Malawi | C, NT | S | 3 | Fluvisols | 600–1000 | 6 |
| Ngwira et al. (2013) | Malawi | C, NT | S | 6 | Luvisols | 600–1000, > 1000 | 22 |
| Ojiem et al. (2014) | Kenya | C | S, R | 2 | – | > 1000 | 90 |
| Rao and Mathuva (2000) | Kenya | C | I, R | 13 | Alfisols | 600–1000 | 39 |
| Riches et al. (1997) | Zimbabwe | C, R | S | 3 | Ferralsols | < 600, 600–1000 | 21 |
| Rusinamhodzi (2015) | Zimbabwe | C, B | S | 2 | Lixisols, Luvisols | 600–1000 | 32 |
| Rusinamhodzi et al. (2012) | Mozambique | NT | S, I, R | 3 | Lixisols | 600–1000 | 24 |
| Shetto and Kwiligwa (1993) | Tanzania | C | S | 1 | – | > 1000 | 8 |
| Sime et al. (2015) | Ethiopia | NT | S | 1 | – | 600–1000 | 16 |
| Thierfelder et al. (2015a) | Malawi and Zimbabwe | NT | S, I | 9 | Luvisols, Arenosols | > 1000, 600–1000 | 18 |
| Thierfelder et al. (2015c) | Malawi | NT | S, I | 9 | Luvisols | > 1000 | 6 |
| Tonye and TitiNwel (1995) | Cameroon | C | S, I | 1 | Kandiudalfs | 600–1000 | 9 |
| Waddington et al. (2007) | Zimbabwe | C | S, I | 13 | Lixisols | 600–1000 | 120 |
| Workayehu (2014) | Ethiopia | C | S, I | 5 | Fluvisols | > 1000 | 15 |
| Zerihun et al. (2014) | Ethiopia | NT | S, I, R | 3 | Nitisols | > 1000 | 10 |

replications. Data from farmers' field trials were also included where each farmer represented one replicate provided that the same trial was established in at least three farms in a location. Our search was comprehensive including the following keywords and their combinations: sustainable intensification, intercropping, conservation agriculture, integrated soil fertility management (ISFM), labor input, labor productivity, reduced tillage, no-tillage, tillage system, crop/maize/corn/sorghum/millet/cassava yield, sub-humid, semi-arid, rain-fed, weed management, water management, profitability, field experiment, and smallholder. Labor input was the key search term and only studies that reported both yield and labor were retrieved. We also contacted authors to get clarifications and additional meta-data for some of the publications. We collected information on moderators such as climate (temperature and rainfall), altitude, soil texture of the experimental site, cropping systems, tillage management, weed control methods, rate of fertilizer, or soil amendment applied, as reported by the primary authors in the publications or in correspondence. These factors were considered to have a significant influence on the magnitude of change of yield. Rainfall was categorized using long-term mean annual precipitation reported by primary authors to form mean annual precipitation (MAP) classes as low (< 600 mm), medium (600–1000 mm), and high (> 1000 mm) based on FAO guidelines (Fischer et al. 2001). Soil type texture was categorized as clay, clay loam, sandy, loamy, and sandy loam (Brown 2003).

Data were collated in MS Excel in the form of treatment mean ($\overline{X}$ ), its standard deviation ($\delta$), and the number of replicates ($n$) for yield as mentioned in the experimental design. However, labor data were often presented as a single value without any statistics. Once collated, we assessed the number of studies and observations present for different crops and technologies. Observations from the same study in the dataset were considered independent data points and included separately if they were from different sites, seasons, main crop, or companion crop to reduce problems with non-independence of data points. Due to data scarcity on most crops, only maize was retained as a focus crop; tillage technologies were ridging, basins, no-tillage, and conventional tillage (generally the baseline technology); and cropping systems were intercropping compared with sole-cropping or rotation compared with continuous monocropping (Table 2). There were very few data from studies that in a stepwise manner addressed multiple production constraints such as low nutrient and water availability and abundance of pests and weeds; hence, evaluation of such effects was not attempted.

## 2.2 Calculations

### 2.2.1 Meta-analysis of maize grain yield

The response ratio (RR) was used as the effect size and was calculated for each observation of maize grain yield as the natural log of the proportional change between the mean of yield for the intervention ($Y_{si}$) treatment (e.g., intercropping, N fertilizers, or conservation agriculture) and the mean of the control ($Y_\mathrm{c}$) group (Rosenburg et al. 2000; Hedges et al. 1999). We chose the RR because of different units used by the primary authors and that none of the observations had zero values. The RR was calculated using the equation:

$$\mathrm{RR} = \ln\left(\frac{Y_{si}}{Y_c}\right)$$

We used a linear regression approach to measure funnel plot asymmetry on the natural logarithm scale of the response ratios as measure of bias in the dataset as suggested by Egger et al. (1997). The influence of moderator variables such as mean annual precipitation (MAP), soil types, tillage type, and cropping system on the yield effect size was computed by meta-regression using the metaphor r-package (Viechtbauer 2010) in R-Studio ver. 1.1.456. The studies were assigned weights based on the inverse of the variance:

$$\mathrm{weight}_i = 1/(\mathrm{variance}_\mathrm{i}) = 1/\mathrm{SD}_\mathrm{i}^{\,2}$$

The weights took into account study variances of treatment effects and the residual of between-study heterogeneity using the procedure described by Borenstein et al. (2009). For each treatment group, we computed an effect size estimate, comparing each pair of treatment and control group. In some cases, the data from the control group was repeatedly used to calculate the effect size estimates, leading to correlated estimates. To address the non-independence of data points, we used the random effects model and also adjusted the effect size variances in cases sharing a common control treatment using the procedure described by Gleser and Olkin (2009). Mean effect size for each moderator was calculated with bias-corrected 95% confidence intervals. Labor data were often from a single measurement and did not contain any error statistics and was thus excluded from bias and meta-regression analyses.

### 2.2.2 Yield-labor relations

We sought to assess whether the interventions for crop improvement would lessen the labor burden of labor-

**Table 2** Terminology used

| | |
|---|---|
| Conventional tillage | Land plowed or hand-hoed to reduce weeds and create suitable tilth |
| No-tillage | No or minimum soil disturbance leaving residues on the soil surface |
| Ridging | Manual or mechanized creation of ridges along the contour, either at the time of land preparation or later |
| Basins | (Manually) dug planting basins intended to concentrate nutrients and water close to the plant |
| Intercropping | Growing of two or more crop species on the same unit of land at the same time |
| Sole cropping | Growing of a crop in single-species stand |
| Rotation | Growing of different crop species in sequence |
| Monocropping | Growing of the same sole-cropped species repeatedly |

constrained smallholders. For better clarity, the change in yield or labor input was assessed as a percentage of the baseline. The percentage response in yield (ΔY) or labor input (ΔL) to intervention compared with the baseline technology was calculated using the equation:

$$\Delta Y\% \text{ or } \Delta L\% = \frac{\overline{X}_{si} - \overline{X}_c}{\overline{X}_c} \times 100$$

Where $\overline{X}_{si}$ is the means of yield or labor input for the intervention treatment (cropping and tillage technology) and $\overline{X}_c$ is the means of yield or labor input of the control group, respectively.

These ratios were presented graphically as a percentage change for easier interpretation. We also calculated the ratio between yield response and labor response (i.e., $\Delta Y/\Delta L$). Our objective was to assess changes (labor and yield) of intervention crop production systems in relation to the baseline which was normally the most common production system in a locality. Labor input was disaggregated by the cropping calendar activities when such data were available, and finally, total labor input was also considered. The influence of moderator variables such as mean annual precipitation (MAP), tillage type, and cropping system on the % yield change was assessed. Initially, the analysis included observations from all relevant studies that tested technologies that could be classified as SI. Hence, these also included studies where, e.g., fertilizer or pest control technologies were tested. To specifically assess the yield-labor relations of the tillage technologies and cropping systems per se, the next step included only a subset of paired observations with the same management in other respects than the tillage or cropping system technology which was compared with its respective baseline treatment. The only exception to this was that different weeding technologies were accepted and the effect of that also taken into consideration.

## 3 Results and discussion

### 3.1 Assessment of bias and maize yield moderators

The contour funnel plot (Fig. 2) using maize grain yield RR was fairly symmetrical around 0, and the Egger's regression test ($z = -1.46$, $p = 0.18$) for asymmetry did not suggest any publication bias in the dataset but data was heterogeneous. Thus, publication bias was not a major concern in our analyses.

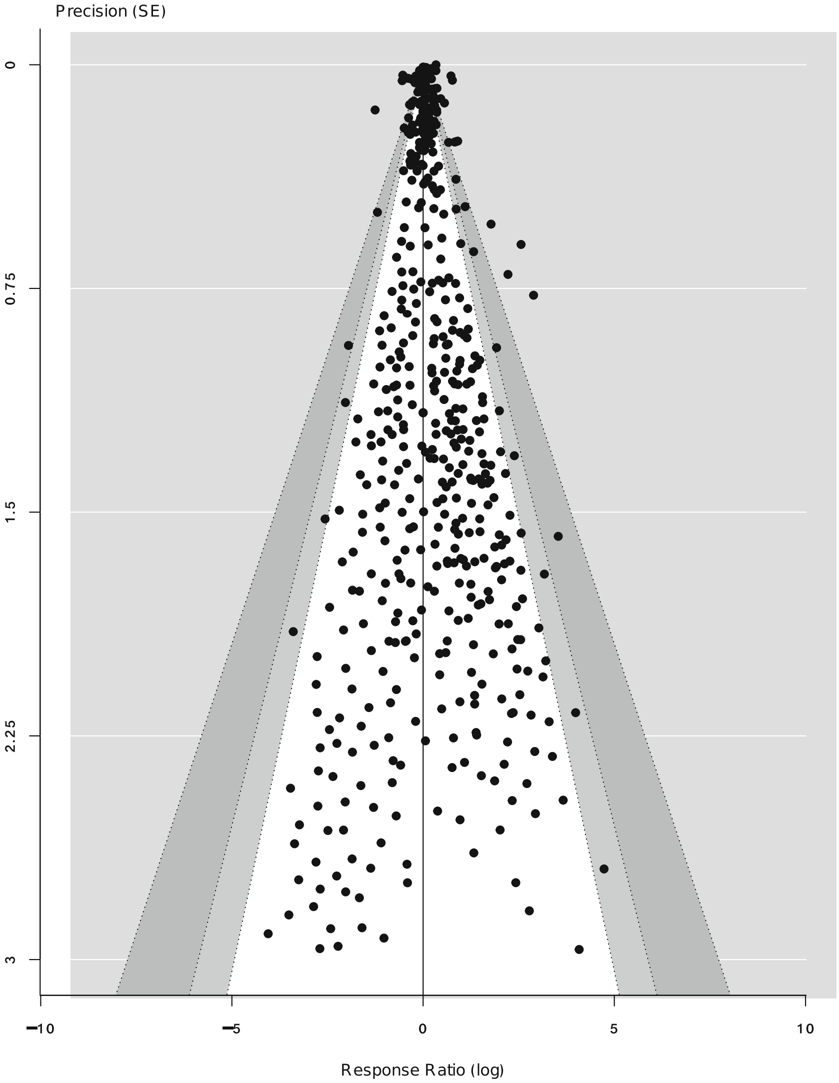
All the MAP categories were significant on the maize yield responses (Table 3). When MAP was lower than 600 mm per year, results suggest that the yield change will be negative (RR = − 0.185) but increased with increased rainfall up to 0.256 when MAP was above 1000 mm per year. In terms of cropping, it is possible to increase maize yield employing any of sole monocropping, intercropping, or rotation systems. However, intercropping was found to be the most beneficial (RR = 0.250) and that benefit was significant. Crop rotation led to the least benefit. Effect size was also affected significantly by soil texture; results showing more benefits were obtained with clay soils (RR = 0.49), followed by sandy loam soils (RR = 0.272), whereas the sandy and loam soils gave negative responses. Ridges (RR = 0.516) and no-tillage (RR = 0.249) resulted in the largest yield benefits for the tillage systems considered. The planting basins did not result in any yield advantage over the baseline tillage system compared (Table 3).

### 3.2 Distribution of yield and labor changes

Absolute maize yields varied widely between studies and seasons with a range of an almost complete failure due to drought or flooding, to 8.1 t ha$^{-1}$ in the baseline systems, and to 9.0 t ha$^{-1}$ in the interventions with a median of 2.2 t ha$^{-1}$ and 2.7 t ha$^{-1}$, respectively. Many different non-maize crops were reported in the intercropped or rotational systems, often with few observations per crop; hence, the analysis was restricted to the maize compartment. Labor was reported in a variety of time and monetary units, precluding compilation of absolute values. The number of studies and observations differed strongly between the tested systems which affected the statistical strength of the analysis. For example, almost all data for planting basins were derived from a study carried out in one location (Rusinamhodzi et al. 2012), and also ridging was presented in a few studies.

Maize yield responses and the concomitant total labor response from paired observations exhibited great variability across the studies. About 50% of the intervention cases recorded 0% or negative yield change when compared with the baseline production system (Fig. 3). The average yield change was + 41% above the baseline although yield changes of up to 10 times were recorded but in very few cases. The average labor change was 0% with a uniform distribution of cases below and above zero (Fig. 3). Results show that new interventions could reduce labor input by as much as − 75% but may also increase it by double (+ 100%) in some cases. A positive change for yield indicates an advantage, for labor input, this means more labor is needed for such a technology and is an undesirable outcome under labor limitation. With opportunities to hire labor, an increase in labor demand can be offset by a relatively larger yield increase and/or high output prices. However, a complete economic evaluation including all possible scenarios of labor input is outside the scope of this paper.

**Fig. 2** Contour-enhanced funnel plot to assess bias in experiments on the effect of sustainable intensification options on crop productivity over baseline production options. The shaded regions represent the 90, 95, and the 99% confidence intervals



## 3.3 Yield change from sustainable intensification options

The average maize grain yield change when using planting basins under sole-cropping in the 600–1000 mm rainfall category was − 12% but was + 71% in the only observation in the > 1000 mm rainfall regime (Fig. 4). There were no data on planting basins associated with intercropping and rotation. In the no-till system, the highest yield increase (+ 20%) was recorded under intercropping in the > 1000 mm rainfall category. The rotation option under no-till led to a large increase (+ 41%) in yield. Under the ridging system, all the tested cropping options under all the rainfall categories increased yield. Sole cropping recorded + 443% under > 1000 mm and rotation systems all gave large increases of + 143% and + 55% for the 600–1000 mm and > 1000 mm rainfall categories respectively (Fig. 4).

Conventional tillage was most often the baseline practice when other tillage options were introduced as interventions for intensification. However, in many instances, conventional tillage was also associated with other interventions such as improved variety, fertilizer application, or intercropping, and this may have increased average yields of this tillage option in the comparison with the other tillage systems when observations from all the publications were included in the analysis. Similarly, sole cropping was also frequently associated with other interventions but was always the baseline for comparing the other cropping systems. It is clear from our study that intervention options were often introduced as a single technology. While such an approach may be desirable with complex technologies and farming systems, it can also limit the possible benefits due to the absence of the potential synergistic effects as reported previously (Sime and Aune 2016; Chivenge et al. 2011; Vanlauwe et al. 2011). Studies employing the component-omission approach and evaluating all the possible combination of practices in the same study may help assess the maximum technology performance across multiple locations (Thierfelder et al. 2015).

**Table 3** Meta-regression and sub-group analysis of studies reporting maize grain yield of sustainable intensification options against baseline scenarios

| | Data pairs (*n*) | Estimate | SE | 95% CI of estimate | | *P* value |
|---|---|---|---|---|---|---|
| | | | | Lower | Upper | |
| Soil type | | | | | | |
| Clay | 132 | 0.487 | 0.087 | 0.316 | 0.658 | < 0.0001 |
| Clay loam | 117 | 0.125 | 0.088 | − 0.047 | 0.296 | 0.154 |
| Loam | 96 | − 0.119 | 0.088 | − 0.292 | 0.054 | 0.177 |
| Sandy | 30 | − 0.057 | 0.418 | − 0.877 | 0.763 | 0.891 |
| Sandy loam | 245 | 0.272 | 0.087 | 0.101 | 0.444 | 0.002 |
| MAP | | | | | | |
| < 600 | 9 | − 0.185 | 0.092 | − 0.365 | − 0.005 | 0.044 |
| 600–1000 | 323 | 0.229 | 0.080 | 0.072 | 0.385 | 0.004 |
| > 1000 | 288 | 0.256 | 0.080 | 0.100 | 0.413 | 0.001 |
| Tillage system | | | | | | |
| Basins | 33 | 0.021 | 0.338 | − 0.640 | 0.683 | 0.949 |
| No-tillage | 146 | 0.249 | 0.087 | 0.077 | 0.420 | 0.005 |
| Ridges | 15 | 0.516 | 0.092 | 0.336 | 0.696 | < 0.0001 |
| Cropping system | | | | | | |
| Intercropping | 242 | 0.250 | 0.083 | 0.087 | 0.412 | 0.003 |
| Rotation | 160 | 0.153 | 0.082 | − 0.008 | 0.314 | 0.063 |
| Sole cropping | 218 | 0.246 | 0.082 | 0.086 | 0.407 | 0.003 |

MAP is mean annual precipitation category, SE is standard error of the estimate, and CI is confidence interval

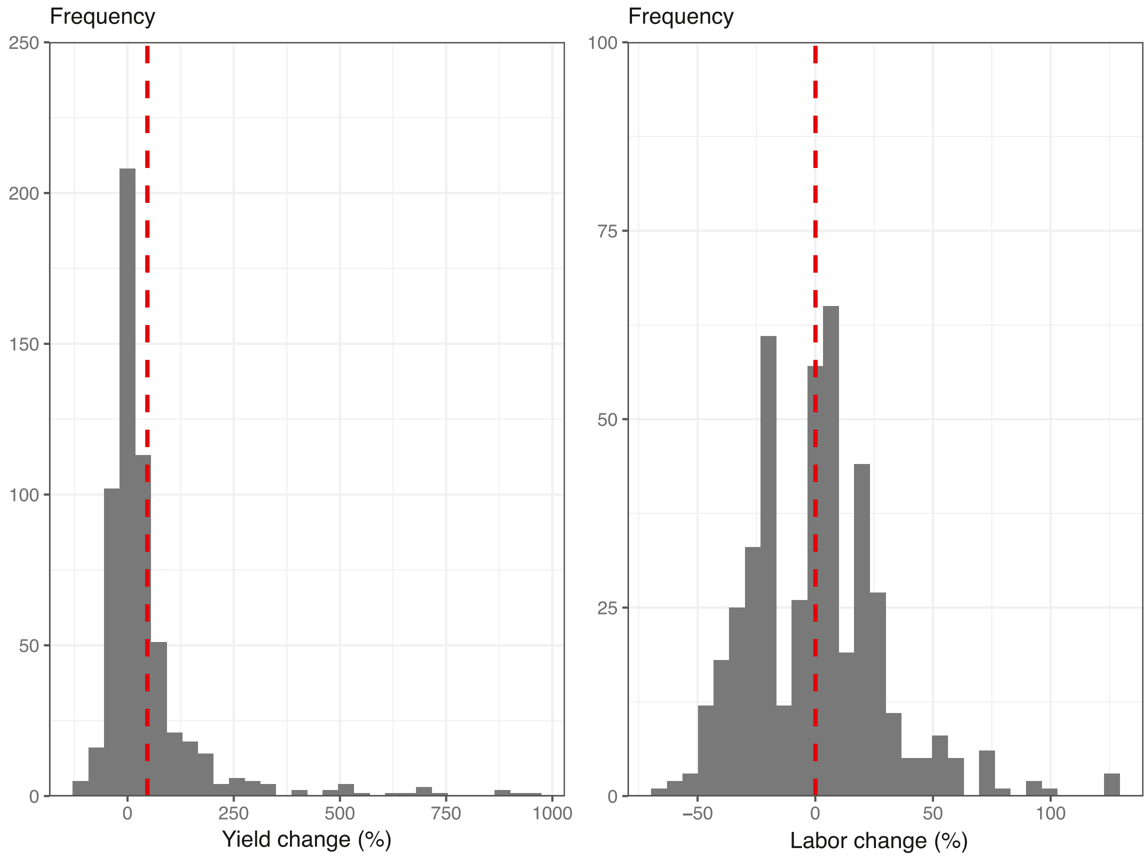


**Fig. 3** The density distribution of the response ratios (RR) for **a** crop yield and **b** labor input. The dashed line is at RR = 0, referred as the line of no effect

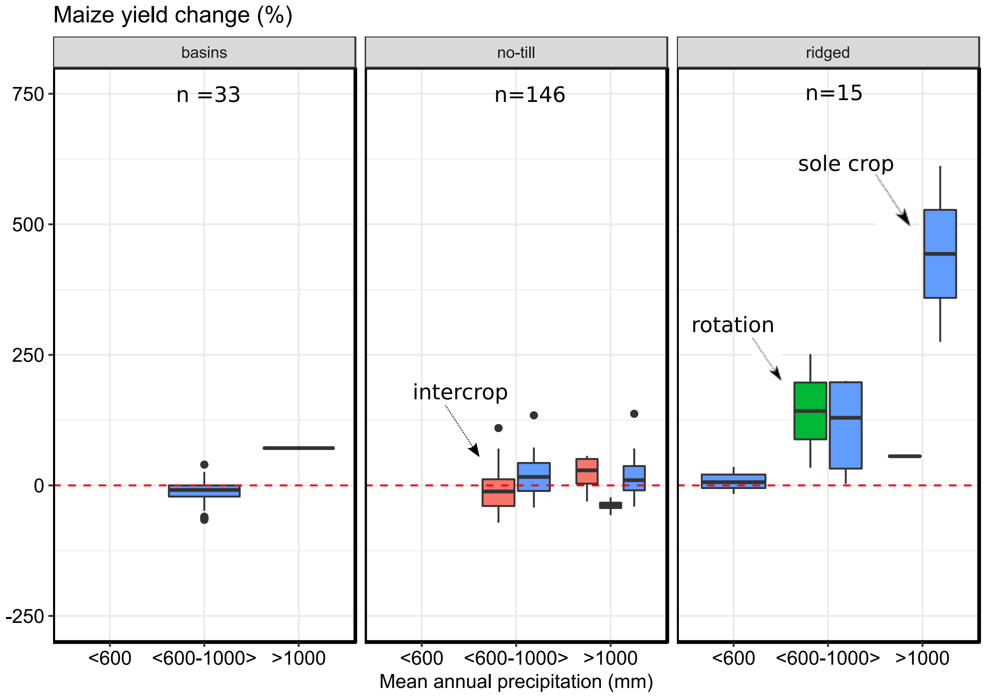


**Fig. 4** Maize productivity change in each of the three intervention tillage systems × cropping system combination in three mean annual precipitation (MAP) classes. The full set of cropping systems was not present in all the MAP classes and tillage combinations

Overall, the reduced tillage practices resulted in small yield benefits above the conventional tillage treatment and productivity was strongly influenced by mean annual precipitation (MAP). Similar results have also been reported from long-term experiments, e.g., Kapusta et al. (1996) reported no significant differences in yield between no-tillage and conventional plowing on poorly drained soils after 20 years of continuous practices. Even the planting basins and ridges which are designed to retain moisture generally showed increased yields at higher rainfall. This is because, under rain-fed conditions, climatic conditions have a greater influence on yield than any other management decisions as has also been reported by Dam et al. (2005). Lal (1997) also observed that maize yield depended more on the amount of rainfall received and its distribution during the season than tillage management. This observation clearly shows that interventions solely based on tillage management are unlikely to increase yield unless combined with other practices and underlines the importance of rainfall (amount × distribution) in the locations from which data were obtained.

Intercropping reduced the yield of maize under low rainfall (< 600 mm), but yields were at par or increased slightly over sole cropping when rainfall was considered sufficient and non-limiting (> 1000 mm). This could be attributed to less competition for moisture between maize and the companion legume crop under high rainfall conditions than under drier conditions (Kermah et al. 2017). The effect of rotation based on this dataset was unclear mainly due to the absence of sufficient detail on how the legume crop residues were managed. However, it is well established that crop rotation is one of the tenets of good agronomic practices and can lead to substantial yield increases of the succeeding cereal through both residual nutrition and control of pests and diseases (Franke et al. 2017).

The studies considered for this review generally did not have different levels of nitrogen (N) within a study, but application rates varied across studies. This meant that the effects of increasing N were confounded as many other factors varied considerably from one location to the other. However, in conservation agriculture-based SI options, the wide C:N ratio and the relatively large amounts of readily decomposable carbon compounds may lead to N immobilization (Cadisch and Giller 1997), thus high N inputs may be required when poor-quality crop residues are used as mulch, especially in the short term. The lack of significant yield benefits from the no-till treatment above the conventional tillage may suggest that the no-till treatment needed more N fertilizer as has been suggested (Vanlauwe et al. 2014). This is because the paired treatments considered in this study often received the same amount of fertilizer between the conventional and the no-till treatment.

### 3.4 Labor input dynamics

Planting basins preparation increased average labor input by + 702% over conventional tillage, whereas no-till reduced land preparation significantly by − 83%, and the ridging system increased land preparation labor input by + 19%. The ridging systems reduced significantly the labor needed for weeding. Sole cropping with ridging reduced labor input for weeding by − 44%, whereas ridging × rotation combination reduced weeding labor by − 32%. No-till similarly reduced average labor input for weeding for rotation and sole cropping (− 82% and − 90%, respectively). In the intercrop option under no-till, average weeding labor input increased by + 18%. The largest and significant increase in labor input of + 35% for weeding was recorded under planting basins. The no-till systems reduced significantly the total labor input. Sole cropping with no-till reduced labor input by − 25% whereas intercropping with no-till reduced total labor input by − 27%. The planting basins increased total labor input significantly (+ 81%) but the ridging system only increased total labor marginally by + 9% in the sole cropping system.

## 3.5 Labor productivity of intensification options

Relations between the yield response and labor input revealed the existence of four situations defined by high yield and low labor demand (Fig. 5). Top left quadrant (HYLL) is characterized by observations of higher yields and a reduction in labor input as a result of the intervention. Top right quadrant (HYHL) represents observations of interventions that increased both yield and labor input. The bottom left quadrant (LYLL) shows the observations of interventions that reduced labor input and yield. The bottom right quadrant (LYHL) shows observations where the interventions increased labor input but decreased yield.

The review of the literature showed that the metrics related to labor input are very different across studies. While returns to labor are widely used, it does not clearly distinguish situations of high labor input and high returns against low input and low returns—i.e., may show the same ratio. In the future, a form of standardization may be needed. Under real conditions of farms, however, activities are not performed in a systematic way and aggregating such labor input is often problematic. For example, farmers may weed a plot over a week with different people involved (young, able, and aged) and during different times of the day, and capturing fully such dynamics if complex. Future studies reflecting on-farm situations need a minimum plot size (beyond those used at experimental stations) and all people involved as well as activities fully characterized.

### 3.5.1 Labor productivity in tillage systems

Our review of studies on tillage systems provided a total of 95 (land preparation labor), 118 (weeding labor), and 138 (total labor) paired observations of tillage technologies compared with a baseline technology and where other management factors were the same except that weed management technology sometimes differed. This baseline was most often conventional flat tillage (albeit with different tools) but no-till technology was also sometimes compared with ridged tillage where this dominated in the area. There were very few paired observations from low-rainfall conditions. Observations of basins were also few, with paired observations only from under intermediate rainfall. However, data indicate that basins require more labor for land preparation and weeding than the conventional baseline (avg + 700% and + 35%, respectively), placing this technology in the two higher-labor demand quadrants (Fig. 6). Both situations of yield increase or decrease were shown, with an average of − 9% compared with the baseline. The ratio between the change in yield and labor inputs ($\Delta Y/\Delta L$) thus averaged 0.16 and 0.66 when considering labor for land preparation and weeding, respectively, indicating that labor demand increased more than yield in the reported studies. The only report on total labor use corresponded to $\Delta Y/\Delta L$ of 0.95.

In contrast, just over 80% of the observations of ridged systems compared with the conventionally tilled were found in the top left quadrant (Fig. 6) for all labor categories. All studies reported lower labor use than in the conventional baseline; labor use for land preparation, weeding, and in total decreased on an average of − 24%, − 48%, and − 33%. Average yield increase was largest (+ 72%) under intermediate rainfall conditions and lower under high rainfall (+ 10%); observations were very few under low rainfall. The $\Delta Y/\Delta L$ across rainfall conditions were 2.0, 3.4, and 2.2 for land preparation,

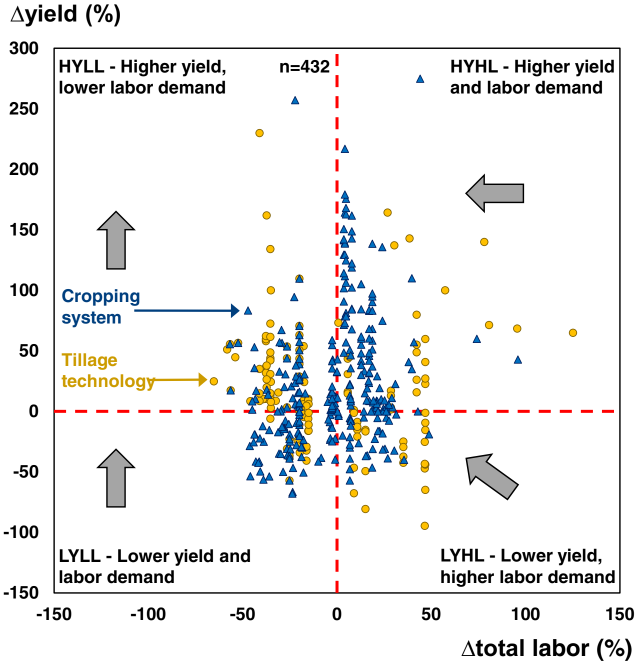
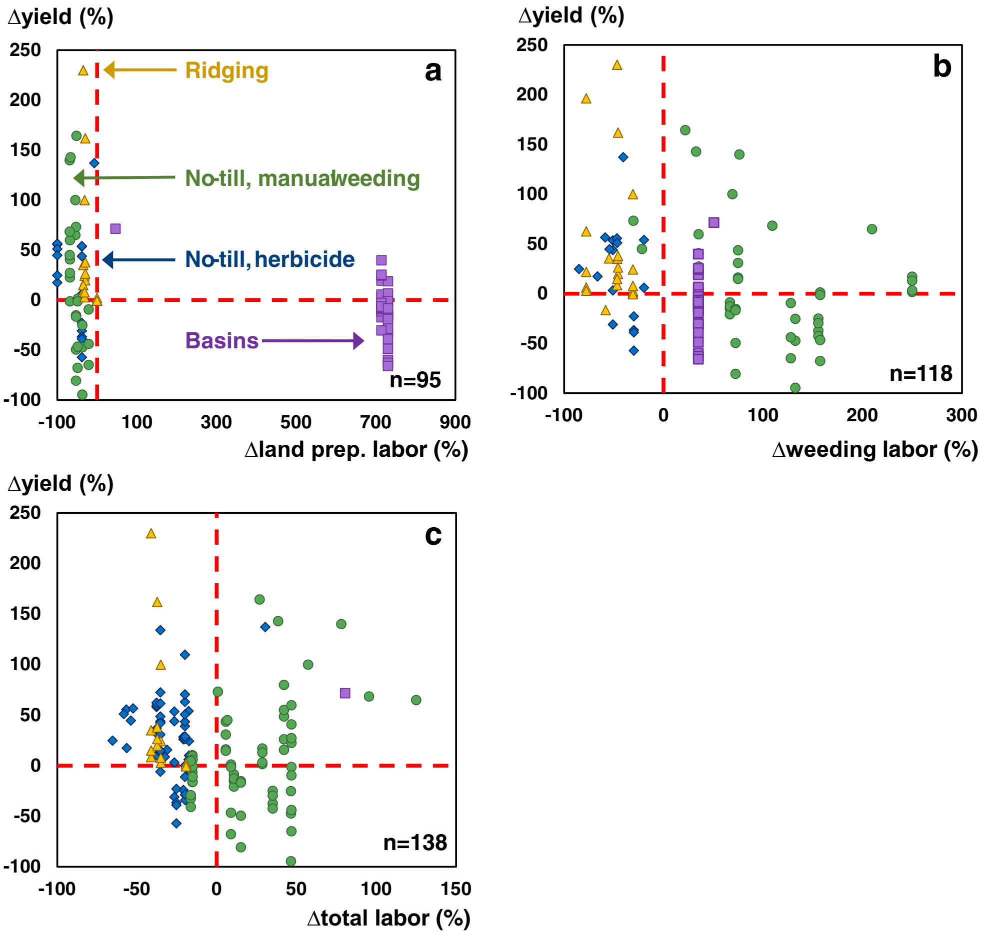


**Fig. 5** The relation between percentage change (Δ) in total labor input and yield for the tested tillage technologies compared with conventionally tilled and cropping systems compared with sole monocropping ($n = 410$). The red, dashed lines indicate lines of no-effect. In case of labor response ratio, it is the line where the intervention has the same labor input as the baseline technology

**Fig. 6** The relation between change (Δ) in **a** labor for land preparation, **b** weeding labor, and **c** total labor input and yield response for planting basins, no-till systems with herbicides or manual weeding, and ridge systems given as % of the conventionally tilled reference point within the same study. The red, dashed lines indicate lines of no-effect. Data are presented across the MAP categories. Numbers of observations for land preparation/weeding/total labor are 33/33/1 for basins, 17/17/59 for no-till with herbicides, 29/45/62 for no-till with manual weeding, and 16/23/16 for ridging



weeding, and in total, respectively, indicating that yield increased more than labor demand.

No-till compared with the baselines showed higher variation and was found in all quadrants (Fig. 6), the pattern being strongly affected by the weed management technology. On average, no-till increased weeding labor by + 109% and total labor by + 14% when manual weeding was done but decreased weeding labor by − 45% and total labor by − 29% when herbicides were used. However, labor for land preparation decreased by an average of − 56% with no consistent difference between studies with herbicides and manual weeding. Yield responses to these technologies varied between MAP categories; under high rainfall conditions, the yield decreased significantly (avg − 12%) under manual weeding but increased significantly when herbicides were used (avg + 11%); under intermediate rainfall, it was not significantly changed under manual weeding but increased (avg + 63%) when herbicides were used. The average $\Delta Y/\Delta L$ across rainfall conditions were thus 1.7, 2.6, and 1.8 for land preparation, weeding, and in total, respectively, when herbicides were used and were 3.3, 0.6, and 0.9 with manual weeding only.

Land preparation through conventional moldboard tillage is labor demanding and for smallholder farmers often possible only during a short time window in connection with the onset of the rains or shortly after harvest of the preceding crop. Access to draught power is generally needed for moldboard tillage and thus often not within the reach for the poorest households or for farmers in geographical areas lacking draught animals. Many farmers therefore have to submit to the back-breaking drudgery of working the land with hand tools. Also, for farmers who can afford to hire draught animals, land preparation and planting may be delayed due to low availability of animals. Weeding is another labor demanding field activity and often uses the largest share of farm labor over the growing season (Vissoh et al. 2004). If staggered planting is practiced, e.g., in order to spread risks under fluctuating and uncertain rainfall, high labor demand for land preparation may entail delayed weeding, thus seriously affecting crop competition for water, nutrients, and light. Substandard weed management has been estimated to cause yield losses of 25–100% in smallholder farming systems in SSA (van Rijn 2000). Hence, revised technologies which decrease labor demand for these tasks are needed.

According to the reviewed studies, the $\Delta Y/\Delta L$ in the range 1.0–6.2 suggests that ridging is likely to be a relatively secure technology for smallholder farmers while offering potentially decreased labor needs. Weeding labor was most clearly decreased by ridging, both when carried out by hand hoe (Mafongoya and Jiri 2015) and by mechanical animal-drawn tools for ridging (Riches et al. 1997) as compared with manual hand tools in a conventional, flat tillage system. Furthermore, the ridging in Riches et al. (1997) was achieved as part of the weeding thus sparing labor for ridging during land preparation. Although the number of studies and observations in the ridging category was small, the average $\Delta Y/\Delta L$ of 3.4 for weeding labor suggests that in the smallholder farming setting, the mechanical weeding achieved by re-ridging can help achieve sufficiently low weed pressure to increase crop yield per invested labor hour substantially even if not always increasing yields per unit area. Decreased labor use and increased net benefits were also found by Shetto et al. (2000) and Shetto and Kwiligwa (1993) when testing animal-drawn weeding tools combined with in-row hand weeding, but careful land preparation was necessary to make the technology successful. Ridging tools are generally constructed for tractor or animal draught power, hence limiting the availability to many smallholder farmers. However, two-wheel tractors may be more within the reach for better-off farmers and farmer groups, although the availability of spare parts and service skills are among factors that may hinder uptake (Bymolt and Zaal 2015). Also, tools managed by human traction, such as hand ridgers, may be used by two persons to create smaller ridges (e.g., Mishra et al. 2016).

Riches et al. (1997) reported increased soil water content in ridged system, presumably because of higher water-capture and infiltration in the resulting micro-topography. The study suggests that under low-rainfall conditions even non-tied ridges along the contour can enhance water infiltration and crop yields while saving especially weeding labor. Larger increases in soil water in tied ridge systems have been found in arid and semi-arid regions (e.g., Brhane et al. 2006; Hulugalle 1990), but we were not able to find studies that also reported labor use and met the pre-determined criteria for inclusion; hence, their relation between labor use and yield change could not be tested.

The data for planting basins, derived almost exclusively from one study carried out under intermediate rainfall (Rusinamhodzi 2015), showed high labor demand. This was especially so for land preparation but also for weeding, in both cases associated with the use of manual labor. The yields did not increase correspondingly in this study, as revealed by the $\Delta Y/\Delta L$ being consistently below 1. High labor demand has also been an impediment to adoption of the zaï system (Schuler et al. 2016), being feasible only where labor opportunity costs are low, land can be worked with reasonable effort before the onset of rains, and/or used for higher-value crops. However, mechanization of zaï construction in Burkina Faso using cattle traction decreased labor use from an average of more than 400 h $ha^{-1}$ to approximately 30 h $ha^{-1}$ (Barro et al. 2005). The observations included here showed an average yield decrease of − 12% in the basin systems compared with the conventionally tilled baseline system. Restricting the use of this type of planting pits to drier sites and/or soils with sufficiently high infiltration capacity to avoid waterlogging in the pits may increase the yield response to positive such as seen by, e.g., Amede et al. (2011), Roose et al. (1999), and Kabore and Reij (2004). Paired with the mechanization of a planting pit construction shown by Barro et al. (2005), this suggests that planting basins may be more beneficial in dry sites than in the study sites included here. However, the independence of draught power of manually dug planting basins which forms part of their promotion (Rusinamhodzi 2015; Andersson et al. 2011; Andersson and Giller 2012) is then irrelevant. Furthermore, in such dry environments, limitations in access to draught animals and their physical condition before the rains start may be a hindrance (Mabuza et al. 2013) unless the scarification performed as part of the mechanization can be done before the dry season.

No-till was, as expected, saving labor during land preparation in the included studies. However, we found no relevant publications with no-till in areas with < 600 mm precipitation where labor use was documented along with other data needed. Nevertheless, the labor savings indicated can be a great advantage especially in areas where the growing season is short and the availability of labor and draught animals is low at the time of the onset of rains and planting (Mupangwa et al. 2017), in particular where soil is hard and difficult to work before the rains (Rusinamhodzi 2015), or the draught animals are in poor condition due to low feed availability during the dry season (Rufino et al. 2011; Mabuza et al. 2013) or unavailable to female-headed households, e.g., due to customary gender roles (Palacios-Lopez et al. 2017).

Whereas no-till consistently increased labor demand for weeding (87% and 44% for medium and high rainfall conditions, respectively) when compared with ridging, the data indicated that no-till compared with conventional tillage increased labor demand for weeding under medium rainfall conditions (avg + 126%) but decreased it under high rainfall conditions (avg − 36%). This apparent difference between MAP classes was traced back to differences in weed management technology; studies performed under medium rainfall were predominantly using only manual weeding in both no-till and the baseline systems (37 out of 38 observations that reported weeding labor) whereas studies performed under high rainfall conditions often applied herbicides in the no-till treatments but only manual weeding in the baseline (14 out of 24 observations). A decisive factor for the outcome in terms of labor use and $\Delta Y/\Delta L$ was thus the use of herbicides and illustrates a shift of input type from labor to cash for herbicide purchase. The choice of weed management technology apparently did not only affect labor use but also the yields. Although the density of weeds was usually not reported, the tendency to lower the yield in the manually weeded no-till systems (in spite of the larger number of work days) than in no-till systems with herbicides suggests that the manual labor invested was insufficient to control the weeds. This may be a contributing cause for the low yield response of the no-till technology found under high rainfall conditions, in addition to previously suggested poor aeration at increased soil water contents (Rusinamhodzi et al. 2012) or low N availability (Vanlauwe et al. 2014).

### 3.5.2 Labor productivity in cropping systems

Studies specifically investigating different cropping systems provided a total of 119 (land preparation labor), 269 (weeding labor), and 272 (total labor) observations of manually weeded rotations or intercropping contrasted with sole cropping. The effect of intercropping on labor demand and yield was highly variable and observations fell into all quadrants for weeding and total labor (Fig. 7). On average, labor demand for weeding and in total were similar in intercropped and sole-cropped systems (+ 4% and − 5%, respectively). The reported labor use for land preparation was, for many observations, the same for intervention and baseline, though, and only plot-wise yields were reported. Yields were on average similar to the baseline (− 4%). The resulting average $\Delta Y/\Delta L$ were 0.78, 0.90, and 1.1 for land preparation, weeding, and in total, respectively.

The relation of maize yield and labor use in rotational systems was also highly variable but a dominance of observations in the top right quadrant showed increased or similar labor use compared to monocropped systems (+ 13%, − 1%, and + 7% for land preparation, weeding, and in total) (Fig. 7). Eighty-nine percent (89%) of the observations of these systems showed increased maize yields (avg + 66%) compared with continuous maize monocropping. The average $\Delta Y/\Delta L$ were 1.4, 1.7, and 1.6 for land preparation, weeding, and in total, respectively.

Despite the lower net area devoted to maize in the intercropped systems, average maize yield was similar to that in the sole-cropped baseline systems, while the system also produced a companion crop. Variation was large, though, reflecting differences in, e.g., rainfall, crop combinations, and crop management in the intervention and baseline treatments. However, although the maize $\Delta Y/\Delta L$ frequently fell below 1 there were also some observations with higher maize $\Delta Y/\Delta L$. This suggests that some intercropping systems may have the potential to increase crop productivity even at decreased labor inputs if tailored to the local agroecology, but that under other conditions in intercropping may bring a yield penalty to the main crop. The acceptable yield penalty will depend on, e.g., the companion crop's yield and market price (if sold) and if it has multiple uses as food and feed and for building soil fertility.

In this review, the variation in tested rotational crops and the variability in labor demand and yield response was large. However, the $\Delta Y/\Delta L$ was more consistently above 1 suggesting beneficial relations between yield and labor demand. Furthermore, literature has shown that rotational systems may increase maize yield significantly (Franke et al. 2017) especially where the alternate crop was green manure (Ojiem et al. 2014). However, even though production systems with green manures may be attractive in terms of yield per unit labor and land, adoption of such systems requires that farmers can invest in a season of green manure crop before reaping the benefits, since they may not contribute to immediate household nutrition. Grain legume rotations, on the other hand, have shown variable effects on the accumulated maize grain yield compared with maize monocropping (Rao and Mathuva 2000; Ojiem et al. 2014). The productivity and value of the rotation crops for home consumption, cash or soil fertility management, and the economic context of the farmers will thus strongly influence the attraction of the rotations.

## 3.6 Implication for SI in sub-Saharan Africa

The perennial challenges such as low fertilizer use, poor markets, labor shortage, erratic rainfall, multiple uses of crop residues, small land sizes, and poor soils on smallholder farms in SSA remain active (Giller et al. 2009). The results reported here have shown clearly that no-till systems can reduce labor input but at a cost of herbicide purchase—meaning that this option could be relevant to relatively wealthy farmers who can afford this initial investment demand. On the other hand, planting basins require very high labor input especially on land preparation but do not entail large capital expenditure (Nyamangara et al. 2014; Rusinamhodzi 2015). In situations of good soil structure such as clay soils, the basins can be maintained for several seasons thus reducing the labor input for land preparation during subsequent seasons. The cost of herbicides can also potentially diminish across seasons, as has been proven that their consistent and correct use result in long-term decrease in weed densities across seasons (Muoni et al. 2013; Muoni et al. 2014; Nyamangara et al. 2014), making basins attractive in the long term under agro-ecological conditions where they give a positive response (i.e., especially in low-rainfall areas).

Literature suggests that the labor demand increases in intercrops compared with sole-cropped systems (e.g., Rusinamhodzi et al. 2012). Our review did not conclusively support this but the variation in the data was large suggesting that confounding factors may have masked the effect. Furthermore, we specifically focused on the maize crop because of the variation in companion crops;

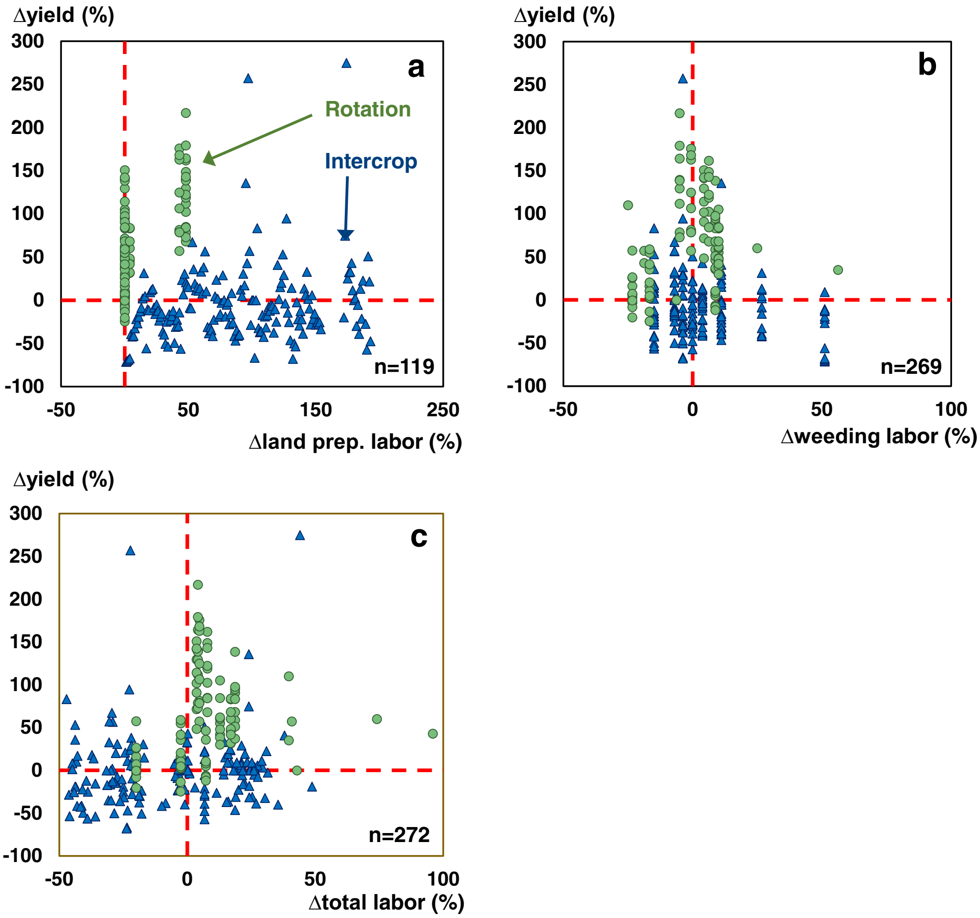


**Fig. 7** The relation between change (Δ) in **a** labor for land preparation, **b** weeding labor, and **c** total labor input for manually weeded intercropping and crop rotation given as % of the monocropped reference point within the same study. The red, dashed lines indicate lines of no-effect. Data are presented across the MAP categories. Numbers of observations for land preparation/weeding/total labor are 23/167/170 for intercrop and 96/102/102 for rotation

including the companion crop in the analysis will increase the labor demand but also the total yield. While labor requirements can be very important for labor-constrained farmers, intercropping systems are more relevant to meet farmers' goals especially in light of population growth and the concomitant decrease in farm sizes, as well as dietary needs of the households. In intercropping systems, increased weeding time has been associated more with hindered movements and the need to take care of crops with different growth rates than with increased weed densities (Rusinamhodzi et al. 2012) but this analysis indicates that this is not always the case. Furthermore, long-term use of fast spreading legume cover crops may actually result in little need for weeding (Mhlanga et al. 2015), and more labor will just be required for planting and harvesting activities to take care of the different planting and harvest dates whereas the total annual labor demand may be reduced.

Overall, the relationships between yield and labor responses have shown the development pathways needed to achieve SI. The data revealed four scenarios: (HYLL) high yield returns—low labor demand, (HYHL) high yield returns—high labor demand, (LYLL) low yield returns—low labor demand, and (LYHL) low yield returns—high labor demand. Data seemed to be fairly spread among the four quadrants. To address these particular situations, several investments are needed to complement the tested technologies: HYHL requires investments in mechanization and herbicides to reduce labor input while maintaining productivity, LYLL requires an increase in fertilizer inputs, improved water and weed and pest management and use of improved varieties. Scenario LYLL requires the combination of, e.g., increased fertilizer inputs, improved water management, improved varieties, and mechanization to reduce labor input, suggesting that the tested technologies were not suitable under the agro-ecological conditions of the studies. HYLL is the most desirable scenario showing SI although additional savings of labor and/or increased yields through attention to crop-limiting factors such as nutrients, water availability, and crop varieties can further improve the yield-to-labor relations. Published studies addressing several constraints in a step-wise manner (e.g., Sime et al. 2015; Sime and Aune 2016) clearly illustrate the benefits that can be gained.

## 4 Conclusions

The relationship between yield and labor input revealed four scenarios: high yield returns—low labor demand (HYLL), high yield returns—high labor demand (HYHL), low yield returns—low labor demand (LYLL), and low yield returns—high labor demand (LYHL). These relationships were significantly affected by rainfall regimes and thus can vary from one season to the next even though the same management intensity can be maintained. The analysis has shown that options can increase the yield-to-labor ratio but conclusions regarding specific practices are not strong due to the low availability of strongly linked yield and labor data, which calls for more original studies. Such studies should preferably report labor data disaggregated by cropping calendar activities to allow analysis of gains or losses in labor productivity for different tasks and at different times of the growing season, and also of potential implications regarding, e.g., gender workload and resource endowment. Going forward, there is also a need to evaluate labor use response rates where more than one limiting factor, e.g., both nutrient and water management, are addressed in a stepwise manner. Though net benefits were observed even in the absence of mechanization or herbicide (ridging, intercropping, and rotations), the greater benefit may be seen with a combination which may also sustain adoption by farmers. To optimize the benefits, these practices should be combined with moisture management, improved varieties, nutrient inputs, and pest control as determined by the local agro-ecological and socioeconomic setting.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

## References

Ajani OIY, Ashagidigbi WM (2008) Effect of malaria on rural households' farm income in Oyo State, Nigeria. Afr J Biomed Res 11(3): 259–266

Amede T, Menza M, Awlachew SB (2011) Zai improves nutrient and water productivity in the Ethiopian highlands. Exp Agric 47:7–20. https://doi.org/10.1017/s0014479710000803

Andersson JA, Giller KE (2012) On heretics and god's blanket salesmen. In: Sumberg J, Thompson J (eds) Contested agronomy: Agricultural research in a changing world. Earthscan, New Yord and London, pp 22–46

Andersson JA, Giller KE, Mafongoya P, Mapfumo P (2011) Diga Udye or Diga Ufe? (dig-and-eat or dig-and-die?) is conservation farming contributing to agricultural involution in Zimbabwe? In: Abstracts of the regional conservation agriculture symposium, Johannesburg, South Africa, 8–10 February 2011, Johannesburg, South Africa. pp 59–59

Baijukya FP, de Ridder N, Giller KE (2005) Managing legume cover crops and their residues to enhance productivity of degraded soils in the humid tropics: a case study in Bukoba District, Tanzania. Nutr Cycl Agroecosyst 73(1):75–87. https://doi.org/10.1007/s10705-005-7262-0

Barro A, Zougmore R, Taonda JBS (2005) Mechanizing the manual zai technique in semiarid areas (Mecanisation de la technique du zai manuel en zone semi-aride.). Cahiers Agricultures 14(6):549–559

Borenstein M, Hedges LV, Higgins JPT, Rothstein HR (2009) Introduction to meta-analysis. Wiley

Brhane G, Wortmann CS, Mamo M, Gebrekidan H, Belay A (2006) Micro-basin tillage for grain sorghum production in semiarid areas of northern Ethiopia. Agron J 98(1):124–128. https://doi.org/10.2134/agronj2005-0148

Brown RB (2003) Soil texture. Institute of Food and Agricultural Sciences. University of Florida, Florida, p 8

Bymolt R, Zaal F (2015) Moving to mechanisation. Mechanisation in maize farming systems in Kenya, Tanzania and Ethiopia. KIT (Royal Tropical Institute), Amsterdam, Netherlands

Cadisch G, Giller KE (eds) (1997) Driven by nature: plant residue quality and decomposition. CAB International, Wallingford, UK

Chapoto A, Jayne TS (2008) Impact of AIDS-related mortality on farm household welfare in Zambia. Econ Dev Cult Chang 56(2):327–374. https://doi.org/10.1086/522894

Chikoye D, Lum AF, Abaidoo R, Menkir A, Kamara A, Ekeleme F, Sanginga N (2008) Response of corn genotypes to weed interference and nitrogen in Nigeria. Weed Sci 56(3):424–433. https://doi.org/10.1614/ws-07-055.1

Chivenge P, Vanlauwe B, Six J (2011) Does the combined application of organic and mineral nutrient sources influence maize productivity? A meta-analysis. Plant Soil 342(1):1–30. https://doi.org/10.1007/s11104-010-0626-5

Dam RF, Mehdi BB, Burgess MSE, Madramootoo CA, Mehuys GR, Callum IR (2005) Soil bulk density and crop yield under eleven consecutive years of corn with different tillage and residue practices in a sandy loam soil in Central Canada. Soil Tillage Res 84(1):41–53

Egger M, Smith GD, Schneider M, Minder C (1997) Bias in meta-analysis detected by a simple, graphical test. BMJ 315(7109):629–634

Fischer G, Van Velthuizen HT, Nachtergaele FO (2001) Global agroecological zones assessment for agriculture in the 21st century. FAO, Austria

Franke AC, Berkhout ED, Iwuafor ENO, Nziguheba G, Dercon G, Vandeplas I, Diels J (2010a) Does crop-livestock interaction lead to improved crop production in the savanna of West Africa? Exp Agric 46(4):439–455. https://doi.org/10.1017/s0014479710000347

Franke AC, van den Brand GJ, Vanlauwe B, Giller KE (2017) Sustainable intensification through rotations with grain legumes in sub-Saharan Africa: a review. Agric Ecosyst Environ 261:172–185. https://doi.org/10.1016/j.agee.2017.09.029

Gathala MK, Timsina J, Islam MS, Rahman MM, Hossain MI, Harun-Ar-Rashid M, Ghosh AK, Krupnik TJ, Tiwari TP, McDonald A (2015) Conservation agriculture based tillage and crop establishment options can maintain farmers' yields and increase profits in South Asia's rice-maize systems: evidence from Bangladesh. Field Crop Res 172:85–98. https://doi.org/10.1016/j.fcr.2014.12.003

Gicheru MN (2016) Barriers and enablers to uptake and implementations of system of rice intensification. A case study of Mwea irrigation scheme in Kenya. MSc, University of Cape Town, Cape Town

Giller KE (2001) Nitrogen fixation in tropical cropping systems, vol 2nd. CABI Publishing, Wallingford, UK

Giller KE, Rowe EC, de Ridder N, van Keulen H (2006) Resource use dynamics and interactions in the tropics: scaling up in space and time. Agric Syst 88(1):8–27. https://doi.org/10.1016/j.agsy.2005.06.016

Giller KE, Witter E, Corbeels M, Tittonell P (2009) Conservation agriculture and smallholder farming in Africa: the heretics' view. Field Crop Res 114(1):23–34. https://doi.org/10.1016/j.fcr.2009.06.017

Gleser L, Olkin I (2009) Stochastically dependent effect sizes. In: Cooper H, Hedges LV, Valentine JC (eds) The handbook of research synthesis and meta-analysis. Russell Sage Foundation, New York, NY, pp 357–376

Grabowski PP, Kerr JM (2014) Resource constraints and partial adoption of conservation agriculture by hand-hoe farmers in Mozambique. Int J Agric Sustain 12(1):37–53. https://doi.org/10.1080/14735903.2013.782703

Guto SN, Pypers P, Vanlauwe B, de Ridder N, Giller KE (2012) Socio-ecological niches for minimum tillage and crop-residue retention in continuous maize cropping systems in smallholder farms of Central Kenya. Agron J 104(1):188–198. https://doi.org/10.2134/agronj2010.0359

Hedges LV, Gurevitch J, Curtis PS (1999) The meta-analysis of response ratios in experimental ecology. Ecology 80(4):1150–1156. https://doi.org/10.2307/177062

Hulugalle NR (1990) Alleviation of soil constraints to crop growth in the upland Alfisols and associated soil groups of the West African Sudan savannah by tied ridges. Soil Tillage Res 18:231–247. https://doi.org/10.1016/0167-1987(90)90063-J

Jama B, Swinkels RA, Buresh RJ (1997) Agronomic and economic evaluation of organic and inorganic sources of phosphorus in western Kenya. Agron J 89(4):597–604. https://doi.org/10.2134/agronj1997.00021962008900040010x

Kabore D, Reij C (2004) The emergence and spreading of an improved traditional soil and water conservation practice in Burkina Faso. EPTD Discussion Paper - Environment and Production Technology Division, International Food Policy Research Institute (114):43 pp.-43

Kapusta G, Krausz RF, Matthews JL (1996) Corn yield is equal in conventional, reduced, and no tillage after 20 years. Agron J 88(5):812–817. https://doi.org/10.2134/agronj1996.00021962008800050021x

Kermah M, Franke AC, Adjei-Nsiah S, Ahiabor BDK, Abaidoo RC, Giller KE (2017) Maize-grain legume intercropping for enhanced resource use efficiency and crop productivity in the Guinea savanna of northern Ghana. Field Crop Res 213:38–50. https://doi.org/10.1016/j.fcr.2017.07.008

Khan ZR, Midega CAO, Njuguna EM, Arnudavi DM, Wanyama JM, Pickett JA (2008) Economic performance of the 'push-pull' technology for stemborer and Striga control in smallholder farming systems in western Kenya. Crop Prot 27(7):1084–1097. https://doi.org/10.1016/j.cropro.2008.01.005

Khan ZR, Pickett JA, Hassanali A, Hooper AM, Midega CAO (2008) Desmodium species and associated biochemical traits for controlling Striga species: present and future prospects. Weed Res 48(4):302–306. https://doi.org/10.1111/j.1365-3180.2008.00641.x

Kwiligwa EM, Shetto RM, Rees DJ, Ley GJ (1994) Weed management-systems based on animal-drawn cultivators for maize production in the southern highlands of Tanzania. Soil Tillage Res 29(4):383–395. https://doi.org/10.1016/0167-1987(94)90110-4

Lal R (1997) Long-term tillage and maize monoculture effects on a tropical Alfisol in western Nigeria.1. Crop yield and soil physical properties. Soil Tillage Res 42 (3):145–160. doi:https://doi.org/10.1016/s0167-1987(97)00006-8

Mabuza ML, Sithole MM, Wale E, Ortmann GF, Darroch MAG (2013) Factors influencing the use of alternative land cultivation technologies in Swaziland: implications for smallholder farming on customary Swazi Nation Land. Land Use Policy 33:71–80. https://doi.org/10.1016/j.landusepol.2012.12.009

Mafongoya PL, Jiri O (2015) Impact of conservation agriculture on weed dynamics and maize grain yield in eastern Zambia. Afr J Agric Res 10(46):4231–4240. https://doi.org/10.5897/AJAR2013.8111

Mhlanga B, Cheesman S, Maasdorp B, Muoni T, Mabasa S, Mangosho E, Thierfelder C (2015) Weed community responses to rotations with cover crops in maize-based conservation agriculture systems of Zimbabwe. Crop Prot 69 (Supplement C:1–8. https://doi.org/10.1016/j.cropro.2014.11.010

Midega CAO, Pittchar JO, Pickett JA, Hailu GW, Khan ZR (2018) A climate-adapted push-pull system effectively controls fall armyworm, Spodoptera frugiperda (J E Smith), in maize in East Africa. Crop Prot 105:10–15. https://doi.org/10.1016/j.cropro.2017.11.003

Mishra A, Singh SRK, Singh A, Borker J, Gour S, Singh SRK, Singh A, Borker J, Gour S (2016) Inventory on women friendly tools. In: ICAR-ATARI, Jabalpur, India

Mucheru-Muna M, Mugendi D, Pypers P, Mugwe J, Kung'u J, Vanlauwe B, Merckx R (2014) Enhancing maize productivity and profitability using organic inputs and mineral fertilizer in Central Kenya smallhold farms. Exp Agric 50(2):250–269. https://doi.org/10.1017/s0014479713000525

Muoni T, Rusinamhodzi L, Thierfelder C (2013) Weed control in conservation agriculture systems of Zimbabwe: identifying economical best strategies. Crop Prot 53:23–28. https://doi.org/10.1016/j.cropro.2013.06.002

Muoni T, Rusinamhodzi L, Rugare JT, Mabasa S, Mangosho E, Mupangwa W, Thierfelder C (2014) Effect of herbicide application on weed flora under conservation agriculture in Zimbabwe. Crop Prot 66:1–7. https://doi.org/10.1016/j.cropro.2014.08.008

Mupangwa W, Mutenje M, Thierfelder C, Mwila M, Malumo H, Mujeyi A, Setimela P (2017) Productivity and profitability of manual and mechanized conservation agriculture (CA) systems in Eastern Zambia. Renew Agr Food Syst 1–15. doi:https://doi.org/10.1017/s1742170517000606

Mutambara J, Ayoola GB, Ejembi EP, Avav T, Masvongo J (2013) Production and productivity of maize subjected to modern and traditional methods of weed control options in Federal Capital Territory, Nigeria. J Agr Ext Rural Dev 5(5):107–114. https://doi.org/10.5897/JAERD2013.0471

Namara RE, Weligamage P, Barker R (2003) Prospects for adopting system of rice intensification in Sri Lanka: a socioeconomic assessment. Research Report - International Water Management Institute (75):vi + 46 pp.-vi + 46 pp.

Nezomba H, Mtambanengwe F, Chikowo R, Mapfumo P (2015) Sequencing integrated soil fertility management options for sustainable crop intensification by different categories of smallholder farmers in Zimbabwe. Exp Agric 51(1):17–41. https://doi.org/10.1017/s0014479714000131

Ngambeki DS (1985) Economic evaluation of alley-cropping Leucena with maize-maize and maize-cowpea in southern Nigeria. Agric Syst 17(4):243–258. https://doi.org/10.1016/0308-521x(85)90037-x

Ngwira AR, Aune JB, Mkwinda S (2012) On-farm evaluation of yield and economic benefit of short term maize legume intercropping systems under conservation agriculture in Malawi. Field Crop Res 132:149–157. https://doi.org/10.1016/j.fcr.2011.12.014

Ngwira AR, Thierfelder C, Lambert DM (2013) Conservation agriculture systems for Malawian smallholder farmers: long-term effects on crop productivity, profitability and soil quality. Renewable Agriculture and Food Systems FirstView:1-14. doi:https://doi.org/10.1017/S1742170512000257

Nyamadzawo G, Wuta M, Nyamangara J, Gumbo D (2013) Opportunities for optimization of in-field water harvesting to cope with changing climate in semi-arid smallholder farming areas of Zimbabwe. SpringerPlus 2:100

Nyamangara J, Mashingaidze N, Masvaya EN, Nyengerai K, Kunzekweguta M, Tirivavi R, Mazvimavi K (2014) Weed growth and labor demand under hand-hoe based reduced tillage in smallholder farmers' fields in Zimbabwe. Agric Ecosyst Environ 187: 146–154. https://doi.org/10.1016/j.agee.2013.10.005

Ojiem JO, Franke AC, Vanlauwe B, de Ridder N, Giller KE (2014) Benefits of legume-maize rotations: assessing the impact of diversity on the productivity of smallholders in Western Kenya. Field Crop Res 168:75–85. https://doi.org/10.1016/j.fcr.2014.08.004

Palacios-Lopez A, Christiaensen L, Kilic T (2017) How much of the labor in African agriculture is provided by women? Food Policy 67:52–63. https://doi.org/10.1016/j.foodpol.2016.09.017

Ransom JK (1990) Weed control in maize/legume intercrops. In: Waddington SR, Palmer AFE, Edje OT (eds) Research methods for cereal/legume intercropping in Eastern and Southern Africa, Lilongwe, Malawi, 1989. CIMMYT, Mexico,

Rao MR, Mathuva MN (2000) Legumes for improving maize yields and income in semi-arid Kenya. Agric Ecosyst Environ 78(2):123–137. https://doi.org/10.1016/S0167-8809(99)00125-5

Riches CR, Twomlow SJ, Dhliwayo H (1997) Low-input weed management and conservation tillage in semi-arid Zimbabwe. Exp Agric 33(2):173–187

van Rijn PJ (2000) Weed management in the humid and sub-humid tropics. Royal Tropical Institute (KIT), Amsterdam

Roose E, Kabore V, Guenat C (1999) Zai practice: a west African traditional rehabilitation system for semiarid degraded lands, a case study in Burkina Faso. Arid Soil Res Rehabil 13(4):343–355. https://doi.org/10.1080/089030699263230

Rosenburg MS, Adams DC, Gurevitch J (2000) Metawin. Statistical software for meta-analysis, version 2. Sinauer associates Inc,, Sunderland, Massachusetts, USA

Rufino MC, Dury J, Tittonell P, van Wijk MT, Herrero M, Zingore S, Mapfumo P, Giller KE (2011) Competing use of organic resources, village-level interactions between farm types and climate variability in a communal area of NE Zimbabwe. Agric Syst 104(2):175–190. https://doi.org/10.1016/j.agsy.2010.06.001

Rusinamhodzi L (2015) Tinkering on the periphery: labour burden not crop productivity increased under no-till planting basins on smallholder farms in Murehwa district, Zimbabwe. Field Crop Res 170: 66–75. https://doi.org/10.1016/j.fcr.2014.10.006

Rusinamhodzi L, Corbeels M, van Wijk MT, Rufino MC, Nyamangara J, Giller KE (2011) A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. Agron Sustain Dev 31(4):657–673. https://doi.org/10.1007/s13593-011-0040-2

Rusinamhodzi L, Corbeels M, Nyamangara J, Giller KE (2012) Maize-grain legume intercropping is an attractive option for ecological intensification that reduces climatic risk for smallholder farmers in Central Mozambique. Field Crop Res 136:12–22. https://doi.org/10.1016/j.fcr.2012.07.014

Rusinamhodzi L, Dahlin S, Corbeels M (2016) Living within their means: reallocation of farm resources can help smallholder farmers improve crop yields and soil fertility. Agric Ecosyst Environ 216: 125–136. https://doi.org/10.1016/j.agee.2015.09.033

Schuler J, Voss AK, Ndah HT, Traore K, de Graaff J (2016) A socioeconomic analysis of the zai farming practice in northern Burkina Faso. Agroecol Sustain Food Syst 40(9):988–1007. https://doi.org/10.1080/21683565.2016.1221018

Sheahan M, Barrett CB (2017) Ten striking facts about agricultural input use in sub-Saharan Africa. Food Policy 67:12–25. https://doi.org/10.1016/j.foodpol.2016.09.010

Shetto RM, Kwiligwa EM (1993) Weed control systems in maize based on animal drawn cultivators In: R. LP, K. L, T. DJ, H. SP (eds) Fourth workshop of the West Africa Animal Traction Network held in Kano, Nigeria, 9–13 July 1990. Published on behalf of the West Africa Animal Traction Network by, Kano, Nigeria. International Livestock Centre for Africa (ILCA) Addis Ababa, Ethiopia, pp 71–78

Shetto RM, Kwiligwa EM, Mkomwa S, Massunga M (2000) Weed control by draft animals: experiences in the southern highlands of Tanzania. In: Starkey P, Simalenga T (eds) Animal power for weed control. A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA). Technical Centre for Agricultural and Rural Cooperation (CTA),, Wageningen

Sime G, Aune JB (2016) Sequential effects of minimum tillage, seed priming, fertilizer microdosing and mulching in maize, semiarid Central Rift Valley of Ethiopia. Exp Agric 52(3):331–345. https://doi.org/10.1017/s0014479715000125

Sime G, Aune JB, Mohammed H (2015) Agronomic and economic response of tillage and water conservation management in maize, central rift valley in Ethiopia. Soil Tillage Res 148:20–30. https://doi.org/10.1016/j.still.2014.12.001

Thierfelder C, Bunderson WT, Mupangwa W (2015) Evidence and lessons learned from long-term on-farm research on conservation agriculture Systems in Communities in Malawi and Zimbabwe. Environments 2(3):317–337. https://doi.org/10.3390/environments2030317

Thierfelder C, Matemba-Mutasa R, Rusinamhodzi L (2015) Yield response of maize (Zea mays L.) to conservation agriculture cropping system in Southern Africa. Soil Tillage Res 146:230–242. https://doi.org/10.1016/j.still.2014.10.015

Thierfelder C, Mutenje M, Mujeyi A, Mupangwa W (2015) Where is the limit? Lessons learned from long-term conservation agriculture research in Zimuto Communal Area, Zimbabwe. Food Security 7(1): 15–31. https://doi.org/10.1007/s12571-014-0404-y

Tonye J, TitiNwel P (1995) Agronomic and economic evaluation of methods of establishing alley cropping under a maize/groundnut intercrop system. Agric Ecosyst Environ 56(1):29–36. https://doi.org/10.1016/0167-8809(95)00634-6

Vanlauwe B, Kanampiu F, Odhiambo GD, De Groote H, Wadhams LJ, Khan ZR (2008) Integrated management of Striga hermonthica, stemborers, and declining soil fertility in western Kenya. Field Crop Res 107(2):102–115. https://doi.org/10.1016/j.fcr.2008.01.002

Vanlauwe B, Kihara J, Chivenge P, Pypers P, Coe R, Six J (2011) Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management. Plant Soil 339(1–2):35–50. https://doi.org/10.1007/s11104-010-0462-7

Vanlauwe B, Wendt J, Giller KE, Corbeels M, Gerard B, Nolte C (2014) A fourth principle is required to define conservation agriculture in sub-Saharan Africa: the appropriate use of fertilizer to enhance crop productivity. Field Crop Res 155:10–13. https://doi.org/10.1016/j.fcr.2013.10.002

Viechtbauer W (2010) Conducting meta-analyses in R with the metafor package. J Stat Softw 36(3):1–48

Vissoh PV, Gbehounou G, Ahanchede A, Kuyper TW, Roling NG (2004) Weeds as agricultural constraint to farmers in Benin: results of a diagnostic study. Njas-Wageningen J Life Sci 52(3–4):305–329. https://doi.org/10.1016/S1573-5214(04)80019-8

Waddington SR, Mekuria M, Siziba S, Karigwindi J (2007) Long-term yield sustainability and financial returns from grain legume-maize intercrops on a sandy soil in subhumid north Central Zimbabwe.

Exp Agric 43(4):489–503. https://doi.org/10.1017/s0014479707003303

Workayehu T (2014) Legume-based cropping for sustainable production, economic benefit and reducing climate change impacts in southern Ethiopia. J Agr Crop Res 2:1):11–1):21

Zerihun AT, Tadesse B, Shiferaw T, Kifle D (2014) Conservation agriculture: maize-legume intensification for yield, profitability and soil fertility improvement in maize belt areas of western Ethiopia. Int J Plant Soil Sci 3(8):969–985

## References of the meta-analysis

Baijukya FP, de Ridder N, Giller KE (2005) Managing legume cover crops and their residues to enhance productivity of degraded soils in the humid tropics: a case study in Bukoba District, Tanzania. Nutr Cycl Agroecosyst 73(1):75–87. https://doi.org/10.1007/s10705-005-7262-0

Franke AC, Berkhout ED, Iwuafor ENO, Nziguheba G, Dercon G, Vandeplas I, Diels J (2010) Does crop-livestock interaction lead to improved crop production in the savanna of West Africa? Exp Agric 46(4):439–455. https://doi.org/10.1017/s0014479710000347

Gathala MK, Timsina J, Islam MS, Rahman MM, Hossain MI, Harun-Ar-Rashid M, Ghosh AK, Krupnik TJ, Tiwari TP, McDonald A (2015) Conservation agriculture based tillage and crop establishment options can maintain farmers' yields and increase profits in South Asia's rice-maize systems: evidence from Bangladesh. Field Crop Res 172:85–98. https://doi.org/10.1016/j.fcr.2014.12.003

Grabowski PP, Kerr JM (2014) Resource constraints and partial adoption of conservation agriculture by hand-hoe farmers in Mozambique. Int J Agric Sustain 12(1):37–53. https://doi.org/10.1080/14735903.2013.782703

Guto SN, Pypers P, Vanlauwe B, de Ridder N, Giller KE (2012) Socio-ecological niches for minimum tillage and crop-residue retention in continuous maize cropping systems in smallholder farms of Central Kenya. Agron J 104(1):188–198. https://doi.org/10.2134/agronj2010.0359

Jama B, Swinkels RA, Buresh RJ (1997) Agronomic and economic evaluation of organic and inorganic sources of phosphorus in western Kenya. Agron J 89(4):597–604. https://doi.org/10.2134/agronj1997.00021962008900040010x

Khan ZR, Midega CAO, Njuguna EM, Arnudavi DM, Wanyama JM, Pickett JA (2008) Economic performance of the 'push-pull' technology for stemborer and Striga control in smallholder farming systems in western Kenya. Crop Prot 27(7):1084–1097. https://doi.org/10.1016/j.cropro.2008.01.005

Kwiligwa EM, Shetto RM, Rees DJ, Ley GJ (1994) Weed management-systems based on animal-drawn cultivators for maize production in the southern highlands of Tanzania. Soil Tillage Res 29(4):383–395. https://doi.org/10.1016/0167-1987(94)90110-4

Mafongoya PL, Jiri O (2015) Impact of conservation agriculture on weed dynamics and maize grain yield in eastern Zambia. Afr J Agric Res 10(46):4231–4240. https://doi.org/10.5897/AJAR2013.8111

Mucheru-Muna M, Mugendi D, Pypers P, Mugwe J, Kung'u J, Vanlauwe B, Merckx R (2014) Enhancing maize productivity and profitability using organic inputs and mineral fertilizer in Central Kenya smallhold farms. Exp Agric 50(2):250–269. https://doi.org/10.1017/s0014479713000525

Mutambara J, Ayoola GB, Ejembi EP, Avav T, Masvongo J (2013) Production and productivity of maize subjected to modern and traditional methods of weed control options in Federal Capital Territory, Nigeria. J Agr Ext Rural Dev 5(5):107–114. https://doi.org/10.5897/JAERD2013.0471

Nezomba H, Mtambanengwe F, Chikowo R, Mapfumo P (2015) Sequencing integrated soil fertility management options for sustainable crop intensification by different categories of smallholder farmers in Zimbabwe. Exp Agric 51(1):17–41. https://doi.org/10.1017/s0014479714000131

Ngambeki DS (1985) Economic evaluation of alley-cropping Leucena with maize-maize and maize-cowpea in southern Nigeria. Agric Syst 17(4):243–258. https://doi.org/10.1016/0308-521x(85)90037-x

Ngwira AR, Aune JB, Mkwinda S (2012) On-farm evaluation of yield and economic benefit of short term maize legume intercropping systems under conservation agriculture in Malawi. Field Crop Res 132:149–157. https://doi.org/10.1016/j.fcr.2011.12.014

Ngwira AR, Thierfelder C, Lambert DM (2013) Conservation agriculture systems for Malawian smallholder farmers: long-term effects on crop productivity, profitability and soil quality. Renewable Agriculture and Food Systems FirstView 1-14. doi:https://doi.org/10.1017/S1742170512000257

Ojiem JO, Franke AC, Vanlauwe B, de Ridder N, Giller KE (2014) Benefits of legume-maize rotations: assessing the impact of diversity on the productivity of smallholders in Western Kenya. Field Crop Res 168:75–85. https://doi.org/10.1016/j.fcr.2014.08.004

Rao MR, Mathuva MN (2000) Legumes for improving maize yields and income in semi-arid Kenya. Agric Ecosyst Environ 78(2):123–137. https://doi.org/10.1016/S0167-8809(99)00125-5

Riches CR, Twomlow SJ, Dhliwayo H (1997) Low-input weed management and conservation tillage in semi-arid Zimbabwe. Exp Agric 33(2):173–187

Rusinamhodzi L (2015) Tinkering on the periphery: labour burden not crop productivity increased under no-till planting basins on smallholder farms in Murehwa district, Zimbabwe. Field Crop Res 170:66–75. https://doi.org/10.1016/j.fcr.2014.10.006

Rusinamhodzi L, Corbeels M, Nyamangara J, Giller KE (2012) Maize-grain legume intercropping is an attractive option for ecological intensification that reduces climatic risk for smallholder farmers in Central Mozambique. Field Crop Res 136:12–22. https://doi.org/10.1016/j.fcr.2012.07.014

Shetto RM, Kwiligwa EM (1993) Weed control systems in maize based on animal drawn cultivators In: R. LP, K. L, T. DJ, H. SP (eds) Fourth workshop of the West Africa Animal Traction Network held in Kano, Nigeria, 9–13 July 1990. Published on behalf of the West Africa Animal Traction Network by, Kano, Nigeria. International Livestock Centre for Africa (ILCA) Addis Ababa, Ethiopia, pp 71–78

Sime G, Aune JB, Mohammed H (2015) Agronomic and economic response of tillage and water conservation management in maize, central rift valley in Ethiopia. Soil Tillage Res 148:20–30. https://doi.org/10.1016/j.still.2014.12.001

Thierfelder C, Bunderson WT, Mupangwa W (2015) Evidence and lessons learned from long-term on-farm research on conservation agriculture systems in communities in Malawi and Zimbabwe. Environments 2(3):317–337. https://doi.org/10.3390/environments2030317

Thierfelder C, Mutenje M, Mujeyi A, Mupangwa W (2015) Where is the limit? Lessons learned from long-term conservation agriculture research in Zimuto Communal Area, Zimbabwe. Food Security 7(1):15–31. https://doi.org/10.1007/s12571-014-0404-y

Tonye J, TitiNwel P (1995) Agronomic and economic evaluation of methods of establishing alley cropping under a maize/groundnut intercrop system. Agric Ecosyst Environ 56(1):29–36. https://doi.org/10.1016/0167-8809(95)00634-6

Waddington SR, Mekuria M, Siziba S, Karigwindi J (2007) Long-term yield sustainability and financial returns from grain legume-maize intercrops on a sandy soil in subhumid north Central Zimbabwe. Exp Agric 43(4):489–503. https://doi.org/10.1017/s0014479707003303

Workayehu T (2014) Legume-based cropping for sustainable production, economic benefit and reducing climate change impacts in southern Ethiopia. J Agr Crop Res 2:1):11–1):21

Zerihun AT, Tadesse B, Shiferaw T, Kifle D (2014) Conservation agriculture: maize-legume intensification for yield, profitability and soil fertility improvement in maize belt areas of western Ethiopia. Int J Plant Soil Sci 3(8):969–985