



Adapting yet not adopting? Conservation agriculture in Central Malawi

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ABSTRACT

Conservation Agriculture (CA) has been widely promoted as a pathway to sustainably intensify agriculture in sub-Saharan Africa (SSA). Yet despite decades of promotion, CA uptake in SSA remains sparse with only few analyses of its impacts on farming and rural livelihoods. This study, which focuses on areas in Central Malawi considered to have a relatively high uptake of CA, uses analyses of satellite images, field observations, interviews with farmers, extension workers and other people involved in CA promotion, as well as a household survey, to investigate how CA has been adapted. We find that the three CA principles – (1) continuous minimum tillage, e.g. no-ridging, (2) permanent ground cover, and (3) crop rotation/intercropping – were not practiced as intended. First, one-third of non-ridged land was tilled during the growing season, and half was again ridged in the following season. Second, unless crop residues were added, the soil's surface of non-ridged plots was usually bare at planting, causing weed control problems, and an increased risk of erosion. Most farmers added large volumes of crop residues to their non-ridged plots. They collected these from the surrounding fields, but this practice severely restricted the size of these plots. Third, crop rotation/intercropping was practiced less when farmers stopped ridging. Thus overall, very few farmers practised all of the three CA principles simultaneously. CA promotion appeared to only increase yields on plots where mulch was added, but this practice is not scalable. CA promotion does not seem to have provided substantial benefits for overall farm productivity, labour-savings or soil conservation.

1. Introduction

Travelling inland from Malawi's lakeshore road in the Nkhotakota district during the dry season, it is easy to observe the common ridge-and-furrow cultivation practice (RFC) that dominates smallholder farming in this country. Yet, in this area one may also observe fields covered with thick layers of dry maize residues scattered through the landscape – an indication that conservation agriculture (CA) is practiced. Initially developed in the Americas, CA is based on three principles: (1) minimum tillage, (2) maintaining ground cover and (3) crop rotation/intercropping (FAO, 2020). It has been promoted globally by numerous organizations to combat land degradation and to raise productivity (Giller et al., 2015; Kassam et al., 2009). Whereas CA has become widely practiced in mechanised, high-input agriculture in the Americas and Australia, where it reduces fuel costs associated with tillage (Giller et al., 2015), its uptake in smallholder farming systems in sub-Saharan Africa (SSA) has been problematic (Giller et al., 2009; Andersson and D'Souza, 2014).

To observe numerous plots with thick layers of ground cover is, for several reasons, remarkable. First, the uptake of CA in African smallholder farming areas has been reported to be rather (s)low, despite decades of promotion by government extension services, numerous NGOs and agricultural research organisations (Andersson and Giller, 2012; Brown et al., 2017b). As a consequence, analyses of CA's impacts on farm practices and rural livelihoods have been scarce. Second, thick layers of crop residues contrast with what most African smallholder farmers who try to practice CA end up with – very little or no ground cover. This is because yields on the continent are usually too low to generate enough crop residues for the 30% ground cover threshold that is often referred to in the CA literature (Vanlauwe et al., 2014). In addition, crop residues used for ground cover are usually needed as livestock feed in SSA (Giller et al., 2009). In this regard, farmers in the lakeside region of Central Malawi have an advantage: for although they tend to burn or incorporate their crop residues while making ridges, they do achieve relatively high yields and they have relatively few livestock (Valbuena et al., 2012). Third, the presence of crop residues offers an

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opportunity to better monitor CA uptake. Amidst definitional diversity regarding what constitutes CA and qualifies as CA adoption, adoption figures are usually more obscuring than revealing. Adoption figures usually end up as counts of the number of farmers practising minimum or no tillage – i.e. the first CA principle only – on some part of their land in any season (Andersson and D'Souza, 2014). The observed fields covered with thick layers of crop residues reflect sunlight and can therefore also be detected on high resolution satellite imagery as accessible on Google Earth (Fig. 1). This appeared to enable an easy, low-cost method of assessing CA uptake in smallholder farming areas beyond the common focus on minimum tillage.

Unfortunately, even an initial exploration of the satellite imagery suggested that the uptake of the second CA principle, maintaining ground cover through crop residue retention, was not straightforward. When comparing a late-dry season timeseries of images, it appeared that residues were being moved between fields and concentrated and spread on the apparent CA plots – something that explains the fields covered with thick layers of dry maize residues. These plots – which appeared not to have been ridged and had mulch added to them – we will refer to as non-ridged, mulch-added plots (NR-MA). They were usually small, and often concentrated along roadsides. We distinguish them from non-ridged plots that had only *in situ* available mulch which we call non-ridged, mulch *in situ* plots (NR-MI). More interestingly still, images taken in successive dry seasons showed that ground cover was usually not maintained in the same plot from one year to the next. Rather, apparent CA plots appeared to be rotated from one plot to the next. This is illustrated in Fig. 1, which also shows that plots that had ground cover in one year often showed signs of having been tilled or burned in the next.

This latter observation is especially important since on-farm experimental studies in Malawi suggest that yield increases from CA should not be expected during the initial year(s) of practicing CA in a field (Ngwira et al., 2014a; TerAvest et al., 2015; Thierfelder et al., 2013b, 2015b). By not practising CA continuously, farmers seemed to postpone the benefits of CA – perhaps indefinitely. On-farm experimental studies also suggest that CA can conserve water and soil, raise profits and save labour (Ngwira et al., 2013; Thierfelder et al., 2013b). Based on this on-farm research, Malawi's National Conservation Agriculture Task Force (NCATF) maintains that CA provides an evidence-based and 'compelling story [to] positively transform Malawian agriculture' (NCATF, 2016). Whether farmers also experience the benefits of CA as found in these on-farm trials depends on how the CA principles have been

integrated in their farming practices. Our observations of satellite images not only reveal the difficulty of *a priori* defining what qualifies as CA adoption. They also raised questions about the effectiveness of the CA integration or adaptation process. The aim of this study is therefore to, (1) understand how CA has been adapted (implemented) in areas of relatively high uptake (of different CA principles), and (2), to assess the consequences of CA adaptation in view of its claimed benefits.

In studying the adaptation of CA – both how the CA principles were actually implemented, and the processes through which they came to be practiced as they were – this study goes beyond typical studies of CA adoption. Such studies focus on establishing the proportion of farmers practicing (some of) the CA principles and pay little attention to the nature and dynamics of the actual practices. Yet, as recent critiques indicate, complex technologies such as CA are not usually adopted as is, but adapted (or locally reinvented) through social processes (Glover et al., 2016, 2019; Ronner et al., 2018). Those promoting CA in SSA – including research and development institutes, government extension and non-governmental organizations – have recognized the need to tailor the CA principles to local smallholder contexts for well over a decade (Erenstein et al., 2012). As argued by Glover et al. (2019), the outcomes of the process of technology adaptation is determined by the actions and constraints of both technology developers/promoters and farmers (end users). We used an empirical approach to understand the actual translation of the CA principles in local CA promotion and by farmers, building on months of field observations, discussions with local informants including CA promotion staff and farmers and a tailored-to-task survey of 286 farming households.

2. Methods

2.1. Study area

2.1.1. Study locations

We made our investigation in areas of long-term CA promotion with so-called on-farm CA demonstration-trials (de Roo et al., 2019), in three Extension Planning Areas (EPAs) in central Malawi. Two EPAs, Zidyana and Mwansambo, are located in Nkhhotakota district while the third, Tembwe EPA, is in the neighbouring Salima district (Fig. 2). Zidyana and Mwansambo EPAs have been the scene of intense and long-term CA promotion, and two EPAs have been associated with a high degree of CA uptake when compared with other projects in SSA (Corbeels et al., 2014). Within the three EPAs, ten areas of approximately 15 km² with

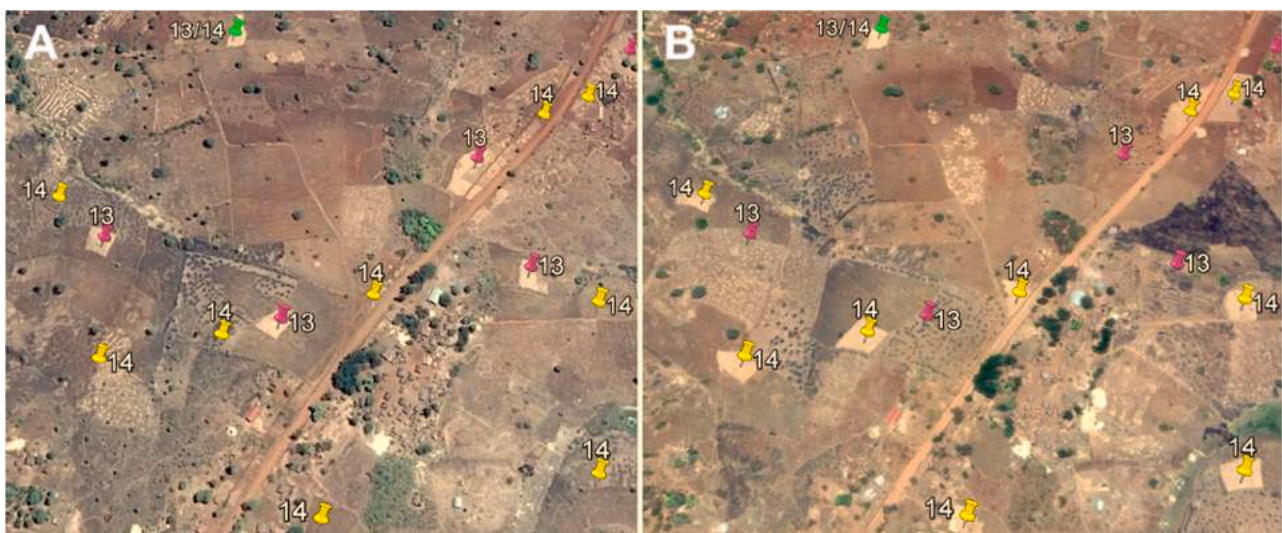


Fig. 1. (A) Apparent CA plots (red pins) with thick layers of crop residues (light patches) in Nkhhotakota district, 7 November 2013. (B) Same area with CA plots (yellow pins) on 16 October 2014. Only one plot (green pin) remained CA from 2013 to 2014. All other apparent 2013 CA plots do not appear to be CA in 2014 (Google Earth). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

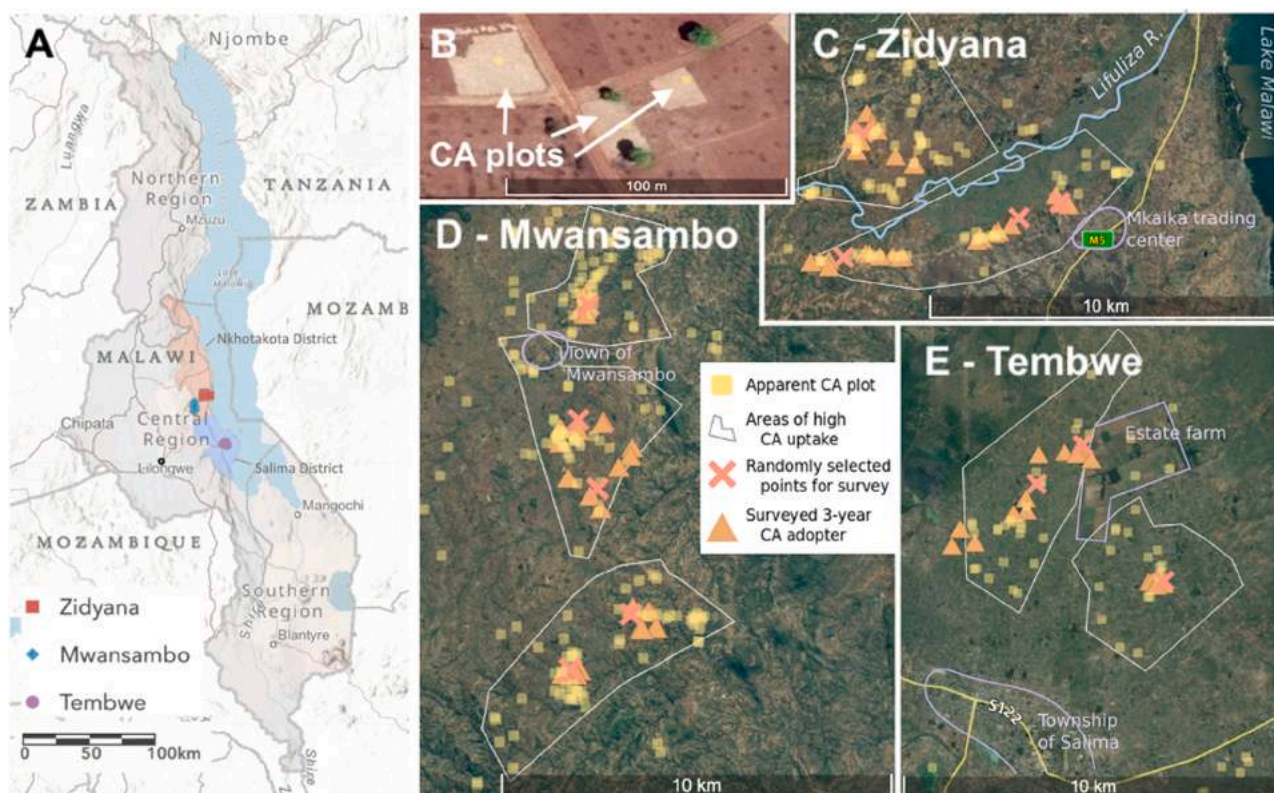


Fig. 2. (A) Location of the three study sites in the Nkhokota and Salima districts. (B) Satellite image showing plots covered with crop residues indicative of CA practices. (C–E) Delimited areas of high CA uptake (based on apparent CA plots) in each EPA. Randomly selected GPS points (red cross) were used to ensure the random selection of CA practising group. Locations of households surveyed who had been practicing CA for three years (orange triangles). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

many apparent CA plots were delimited using satellite images captured by the Worldview 3 satellite in 2013 and 2014 (available on Google Earth). CA plots, including on-farm demonstration-trials, were identifiable in these images as the thick layers of residues on them reflect sunlight (See Fig. 1 and Fig. 2B). Non-ridged plots with little residues cannot easily be distinguished from ridged plots on satellite imagery. These images therefore cannot be used to estimate overall CA adoption as fields without thick layers of crop residues are likely to be missed. Satellite imagery is only helpful to identify one emergent type of CA practice, NR-MA. The 15 km² areas, characterised by many NR-MA plots, were selected to include land near the on-farm CA demonstration-trials. These areas were also selected with a view to ensuring different topographies (hilly or flat, along rivers or not), soil types and population densities were represented. Seven of the ten polygons were visited and included in a survey (see white polygons Fig. 2C-E). The remaining three polygons were not included due to logistical reasons.

2.1.2. A description of the study area

Although groundnut production was common in Zidyana and Mwansambo, rain-fed maize dominates cropping systems in the studied districts. Most crops in the area are grown using ridge-furrow cultivation (RFC). RFC involves planting the crop on ridges spaced approximately 90 cm apart. Before planting in the next season, hoes are used to split the ridges and rebuild them in the place of the previous year's furrow. Rebuilding ridges during the growing season (locally referred to as banking) is commonly practiced to control weeds. The Tembwe site lies on flat land, while Zidyana was on flat and undulating land and is crossed by the Lifuliza River where irrigation and rice cultivation are possible. Mwansambo lies on undulating to hilly land. Rain falls during a five-month growing season that begins in November and ends in April.

Tembwe receives around 800–1000 mm per year while Zidyana and Mwansambo receive around 1000–1300 mm (Thierfelder et al., 2013b). The three EPAs are positioned between 500–750 meters above sea level. The study sites are likely on calcimorphic soils (Reynolds, 2000) with Tembwe EPA on *stagnsols* of a sandy loam texture (Nyagumbo et al., 2016) and Mwansambo and Zidyana to the north on sandy clay loam (*haplic lixisols*) (Thierfelder et al., 2013b).

CA promotion first began in each EPA in 1996/1997 with a government-led minimum-tillage project that ran into the early 2000s (Mloza-Banda and Nanthambwe, 2010; Nkunkia, 2003). Since 2004/2005 the non-governmental organization (NGO) Total Land Care (TLC) has promoted CA in Mwansambo and Zidyana EPAs in collaboration with the International Maize and Wheat Improvement Centre (CIMMYT) and the Malawi Government (MG) extension service. In Tembwe, CIMMYT on-farm trials began in 2010 in collaboration with the Malawi Government extension services. Other non-governmental organizations also promoted CA for some years in the study area, including Concern Worldwide in Zidyana and Mwansambo, and Malawi Lake Basin (since 2010), Assemblies of God, Adventist Development and Relief Agency and Land O'Lakes International Development in Tembwe.

2.2. The household survey

Next to analyses of satellite imagery, fieldwork for this study started with extensive observations in farmers' fields, CA demonstration-trials, and informal and semi-structured interviews with farmers, extension workers and other people involved in CA promotion. These informed the design of a household survey that was conducted during a three-week period in late June and July of 2016. The survey was conducted by four experienced enumerators who were trained to administer the questionnaire using tablets equipped with Open Data Kit software.

Household heads or their spouses (or in rare cases another adult in the household) were asked questions about the household's socio-economic and demographic characteristics, farming practices, wealth, and food security situation.

Two kinds of households were selected for the survey – *CA practising households* and *neighbouring households*. *CA practising households* were purposefully sampled to ensure CA practices could be studied. *CA practising households* were defined as households having farmed without ridging and with some (i.e. 30 % or more) ground cover at planting time on at least part of their farm for the past three years. Farmers who banked (rebuilt ridges on) all their non-ridged plot(s) in 2015/16 were not considered to be practicing CA. The *CA practising households* were sampled as follows: (1) One to three points (depending on the number and spread of the *CA practising households*) were randomly selected on a map of each of the seven 15 km² areas; (2) These points were then located on the ground using a GPS device, and; (3) The nearest six or 12 (depending on logistics) *CA practising households* were identified with the help of local extension officers or lead farmers. *Neighbouring households* were selected as the third and sixth nearest homesteads to the *CA practising households*. Thus, the number of *neighbouring households* was twice the number of the selected *CA practising households*. Occasionally, when no adult in the third or sixth nearest homestead was available for interview, the next nearest neighbour was selected. The *neighbouring households* were selected to understand the farming practices prevalent at large within the high CA uptake areas. Farming practices of *neighbouring households* included both RFC and (components of the) CA practices. Neither the CA practicing nor the neighbouring households were selected to measure rates of CA adoption per se.

In total, 286 households were interviewed. Of these, 11 interviews were excluded due to either deviations from the sampling protocol (enumerators having been introduced to CA-practising households other than those nearest to a predefined point) or to inconsistent responses on important topics (such as whether or not the household had practiced CA in a given year). The final number of households analysed was 275. The number of plots belonging to these households was 859. Of the 275 households, 99, 101 and 75 were located in Mwansambo, Zidyana and Tembwe EPAs respectively.

The survey questions dealing with farming practices covered the households' history of tillage and management practices implemented on each of their plots. Enumerators and respondents drew maps of each farm to ensure that each plot was included in the survey and described distinctly. More detailed questions about management (e.g. tillage history, crop residue management, harvest quantities, planting date) were asked for focus plots grown to maize. These focus plots were selected by enumerators – one for each of three different cultivation practices: Ridge-and-Furrow Cultivation (RFC), Non-Ridged plots with Mulch Added (NR-MA), and Non-Ridged plots with Mulch In-situ (NR-MI). The selection of RFC focus plots within each farm was made randomly, while the selection of non-ridged focus plots favoured those that had not been ridged for the longest period of time. In total, there were 388 focus plots. Harvest quantities were reported in 50 kg bags of shelled maize or in oxcarts of unshelled maize. As farmer-reported plot sizes have been noted to be inaccurate (Carletto et al., 2015), GPS-measurements of the corner points of many of the focus plots were also collected. These corner points were then plotted over aerial photographs (5–10 cm per pixel) captured with an unmanned aerial vehicle (an eBee designed by SenseFly) of the study area. Where the points matched well with the fields visible on the aerial photographs, the area of the plot was calculated. In total, the plot size of 202 of 388 focus plots were measured using this geographic information systems (GIS) method. Farmer-reported plot sizes were also recorded ($n = 859$). Farmers often overestimated their plot sizes, especially for their smaller plots. The relationship between farmer reported plot sizes and GIS measured plot sizes is shown in Figure S1 of the Supplementary Material.

2.3. Data analysis and statistics

Data analysis was performed using R version 3.6.1 (R Core Team, 2019). Linear mixed models were used to compare the cultivation practices (RFC, NR-MA and NR-MI) at the plot level in terms of input rates (kg/ha), labour (6 -h working days per ha), planting dates and yield (kg/ha). Farm and location (three EPAs) were included as random effects in these models. Input rates for nitrogen (N) and phosphorus (P) were calculated in kilograms per hectare using the reported amount of fertilizer applied (in kilograms), the nutrient content of each fertilizer, and the GIS-measured maize focus plot area. To improve the fit of the models comparing nutrient rates, N and P rates were square root transformed and outliers more than 3.5 standard deviations from the transformed mean were removed (two and three outliers for N and P respectively). Similarly, for the model comparing labour inputs, labour data was log transformed to better ensure homoscedasticity. Reported planting dates were used as reported, though when a range of dates was provided, the midpoint of the range was calculated. Yields were calculated from the reported number of 50 kg bags of shelled maize or the number of oxcarts. Extension officers reported that oxcarts hold about 150 kg of maize, however, oxcart reported yields were substantially lower than yields reported in bags. Thus, we also calculated yields using the assumption that the reporting unit (oxcarts or 50 kg bags) did not, on average, affect yields. In this case oxcarts are assumed to carry 245 kg of maize. Yield calculations were made both using only GIS measured focus plots and using all focus plots (both GIS measured and farmer reported plots). Five plots with yields reported over 10,000 kg/ha were excluded from the analysis. The yield data was also logarithmically transformed to ensure homoscedasticity.

In addition to the linear mixed models, generalized linear mixed models were used to compare the proportion of plots with different management characteristics. Within these models, location (three EPAs) was included as a random effect and the response was modelled as a binomial distribution. The factors included in each model are presented in the results section. In all models, the Tukey method was used to correct for the family-wise error rate. Model estimates of the main effect (i.e. cultivation practice) and their 95 % confidence intervals, as well as the p-values of pairwise comparisons were obtained using emmeans function of the emmeans package (Russell, 2019).

3. Results

3.1. The adaptation of CA principle 1: Minimum or no tillage

In line with CA promotion in central Malawi, many farmers planted parts of their farms without making new ridges. Locally this was called '*ntaya khasu*', meaning, '*throwing away the hoe*.' Within the survey, 45 % of the *neighbouring households* ($n=185$) had at least one non-ridged (NR) plot – up from 5% a decade earlier (Fig. 4A). (This group of *neighbouring households* provides an estimate of farmers' practices at large in these areas of high CA uptake.) Farmer uptake of NR differed substantially between the three EPAs (Fig. 4B). In Mwansambo, Zidyana and Tembwe EPAs, 67 % ($n = 66$), 40 % ($n = 68$) and 25 % ($n = 52$) of *neighbouring households* reported practicing NR in the studied season respectively. These differences between the EPAs largely reflect the time and intensity in which CA was promoted. Yet, practicing NR often did not mean the first principle of CA (continuous minimum tillage) had been implemented.

As suggested by the satellite images, CA was often not practised continuously. We asked farmers about the tillage history of each of their plots and found that only 46 % of the 2015/2016 NR plots also had been NR in 2014/2015 ($n = 243$). When adopting an area perspective, we found that 71 % of the NR land of *neighbouring households* in the 2015/2016 season (36.4 ha) had been ridged in the previous year. Similarly, 60 % of the *neighbouring households*' NR land in the 2014/2015 season (26.8 ha in total), was again ridged before the start of the 2015/2016

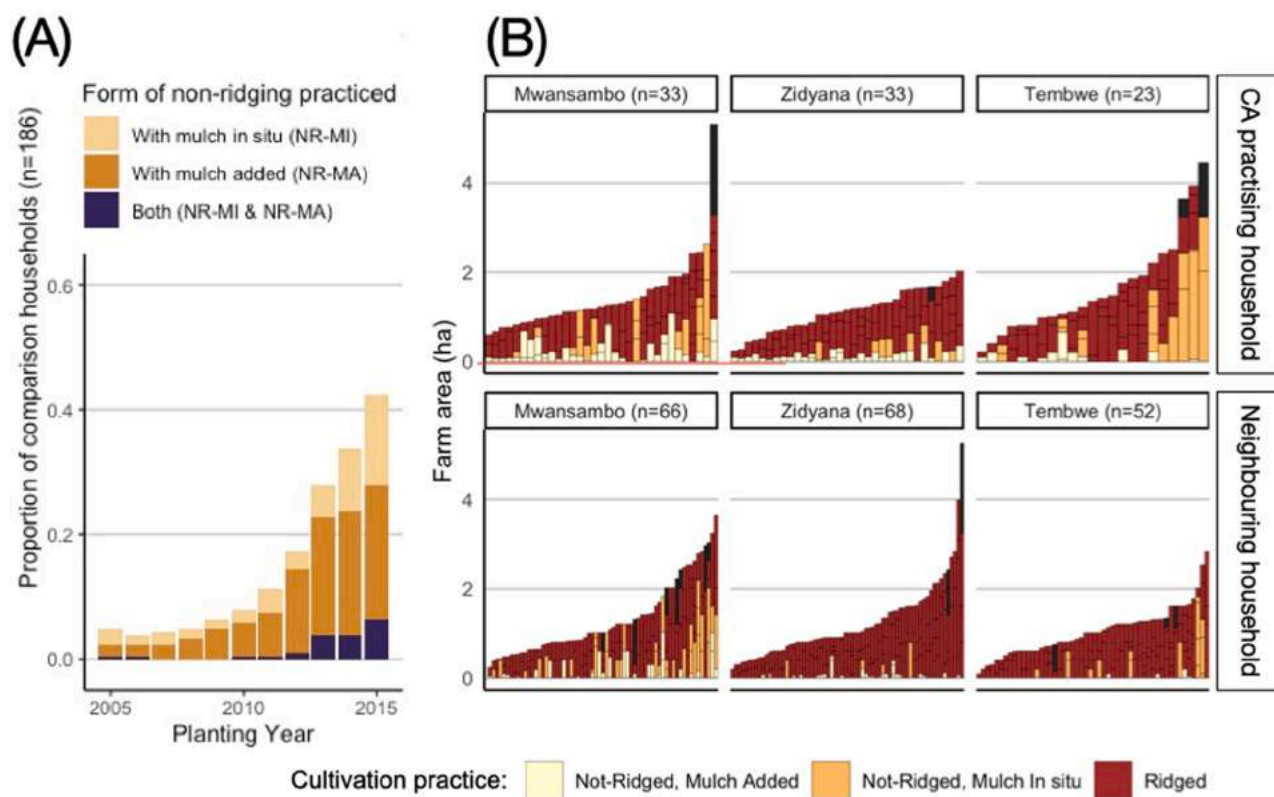


Fig. 4. (A) Not-Ridged with Mulch Added and Not-Ridged with Mulch In-situ uptake by year (neighbouring households), and; (B) by farm area. (B) Vertical bars indicate the land allocated to different cultivation practices per surveyed farm for the 2015/16 growing season. Farms are separated by EPA and selection group (CA practising and neighbouring household).

season. These numbers give an indication of the discontinuous nature of NR at large. NR was not practised continuously due to the shifting of NR plots within farms and the farm-level abandonment of NR. Thirty seven percent of three-year CA practising households' land was NR in 2014/2015 but ridged in 2015/2016 – indicating that shifting of NR plots was common among households with CA experience. Farmers gave different reasons for shifting their NR plots within their farms, including spreading the benefits of CA across their farm and avoiding the build-up of pests such as white grubs. Farm-level abandonment of NR was also quite common. For instance, 30 % of the *neighbouring households* reported having practised NR in 2014/2015 but no longer in 2015/2016 ($n = 63$).

Beyond NR not being practised continuously, banking (e.g the remaking of ridges) on NR plots was also common. Banking is done to control weeds and to prevent lodging, by returning soil that has been washed into the furrows onto the earlier made ridge (Orr et al., 2002). In total, farmers reported that about 32 % of the NR focus plot area was banked – another divergence from the first CA principle.

3.2. The adaptation of CA principle 2: maintaining ground cover

Maintaining permanent ground cover is the second principle of CA. Farmers' implementation of this principle was also unorthodox. In general, two practices for managing crop residues had emerged. One sought to achieve maximum ground cover by the addition of mulch (NR-MA). Whereas in the other, mulch was kept *in situ* (NR-MI).

3.2.1. Farming with added maize residues (NR-MA)

As hypothesized from satellite images, farmers usually added large quantities of mulch to their NR plots. Indeed, 77 % of ($n = 160$) households that practised NR added mulch to their NR plot(s). NR-MA plots were typically covered with layers of maize stalks of 10–20 cm

thick. Mulch was added during the dry season and involved collecting, storing, piling, and neatly laying (a.k.a. *'thatching'*) the crop residues side-by-side to facilitate planting when the rains arrived (Fig. 3A–C). Such thick layers continued to provide ground cover during the growing season (Fig. 3D). Locally, this was called *'ulimi wa mapezi'*, or *'farming with maize stalks'*. CA promoters had promoted laying thick layers of mulch for many years. Even the CA demonstration plots covered by the survey (15 out of 18) usually had residues added to them. Further, the presence of the mulch was often a requirement for input support. As one farmer put it, *'People that lay the crop residues are normally told by the NGOs and/or government and they do this after being promised inputs for their mulched plots.'* Farmers reported that the thick mulch layers provided benefits such as: (1) smothering weeds; (2) increasing soil organic matter – farmers said the residues decomposed into manure; (3) ensuring sufficient ground cover to reduce erosion, and; (4) holding moisture during dry spells.

The NR-MA plots had substantially more ground cover than the 30 % threshold associated with CA (Kassam et al., 2009). Using images of different levels of ground cover (see Supplementary Material, Figure S2), 63 % of farmers indicated their NR-MA focus plots had 100 % ground cover at planting. An additional 32 % reported that most (approximately 80 %) of the ground was covered at planting. These mulch layers were achieved by importing large quantities of crop residues into the plots. On 70 % of NR-MA focus plots ($n = 130$), half or more of the residues were reported to come from outside the plot.

Because farmers imported such large volumes of crop residues, the availability of these crop residues became main factor limiting the land area on which they practised NR-MA. Seventy-six percent of respondents ($n = 96$) with NR-MA on less than 50 % of their farm area, indicated the extent of NR-MA was constrained due to having *'not enough residues'* or *'not enough labour [for carrying mulch]'*. The typical extent to which farmers practiced NR-MA was very small. Of all farms in the three EPAs

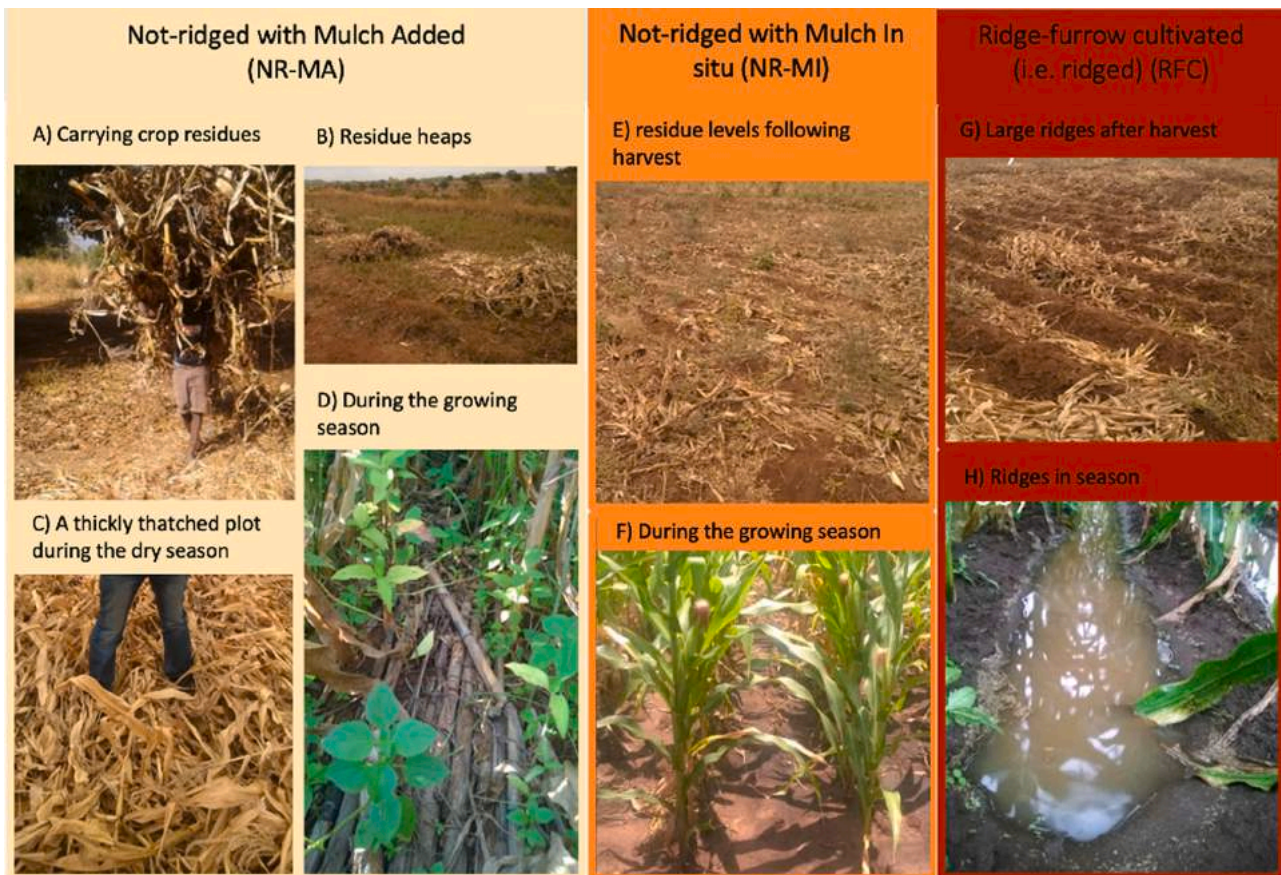


Fig. 3. (A-D) Late and dry season photos of Not-Ridged with Mulch Added (NR-MA) plots; (E-F) Not-Ridged with Mulch In-situ (NR-MI) plots, and; (G-H) Ridge-Furrow Cultivated plots (RFC). Photo (A): William Simwanza. Photo (B-H): Tristin Bouwman.

that had NR-MA plots, the median (and interquartile range) of the proportion of farmland covered by NR-MA was only 13 % (7–24) ($n = 123$). This proportion is likely an overestimate since farmer reported NR-MA plot sizes were usually overestimated by a factor of two (See Supplementary Material Figure S1).

3.2.2. Keeping mulch in situ (NR-MI)

A second style of CA had also emerged, most likely in response to a switch in the CA promotion message. Around 2013, CA promotion started to discourage adding crop residues to CA plots. As a government official at the Salima Agricultural Development Division put it, 'Previously, CA meant covering the field, but [now] minimum soil disturbance is the main pillar of CA.' Now mulch was to be retained *in situ* within the plots. The switch was primarily a response to the limited extent to which farmers practised NR-MA. Concerns that adding residues was facilitating pest and disease transfer also seem to have played a role.

Since 2013, many farmers practise NR-MI (Fig. 4A). They were also able to practice NR-MI on larger areas (Fig. 4B). This was especially the case in Tembwe and Mwanambo (Fig. 4B). In Zidyana, extension officers were more sceptical of the merits of NR-MI; they worried that the yield benefits would be lost. Overall, NR-MI practising households reported that 40 % (median) of their farms were cultivated as NR-MI. As a result, on a land area basis, NR-MI was more common than NR-MA. It covered 14 % of all the land in the survey (224 ha) while NR-MA only covered 8%. Of land belonging to *neighbouring households* – which provides an estimate of uptake at large – 12 % was NR-MI and 5% was managed as NR-MA.

Yet, as shown in Fig. 3 F, ground cover in NR-MI plots was often very sparse. On 60 % of all NRM-MI focus plots ($n = 45$), ground cover was reported as 'none', at planting time. Further, among *neighbouring*

households, 70 % of focus plots were reported to have less than 30 % ground cover at planting ($n = 23$). (Since the 3-year CA practising group was defined as having practiced NR with 30 % ground cover, the *neighbouring households* provide a more accurate estimate of ground cover on NRM-MI plots). The lack of ground cover can be attributed to the low production of biomass and to substantial losses of biomass. As Fig. 5A shows, about half of the NR-MI plots were reported to lose most or all of their crop residues. The main causes of these losses were termites, livestock, burning at land clearing, burning by mice hunters and removal for NR-MA plots (Fig. 5B). Rodents, which are an important protein source in Malawi, frequently reside beneath piled maize at the end of the growing season. Mice hunters frequently burn crop residue piles to drive them out and catch them. Overall, termites and livestock – quite unavoidable causes of residue loss – were most commonly reported.

Still, practising NR-MI appears to have contributed to modest increases in crop residue retention. While 51 % of NR-MI plots lost at least half of their crop residues during the dry season, such a level of crop residue loss occurred on 75 % of the RFC plots (Fig. 5A). The main cause of the difference appears to be burning at land clearing. Nevertheless, crop residue retention was also practiced in RFC with residue incorporation being reported on 44 % of RFC focus plots.

Without ground cover to suppress weeds NR-MI can lead to weed control problems as was observable in the study area. Of the farming households that reported to have practised NR-MI ($n = 92$), 66 % agreed or strongly agreed with the statement, 'If you do not ridge and don't carry crop residues [e.g. practice NR-MA], you will have too many weeds'.

To help control weeds, herbicides had been promoted with CA (Bouwman et al., 2020). They were reportedly applied on 44 % of NR plots ($n = 243$). While their use may have been most necessary on NR-MI

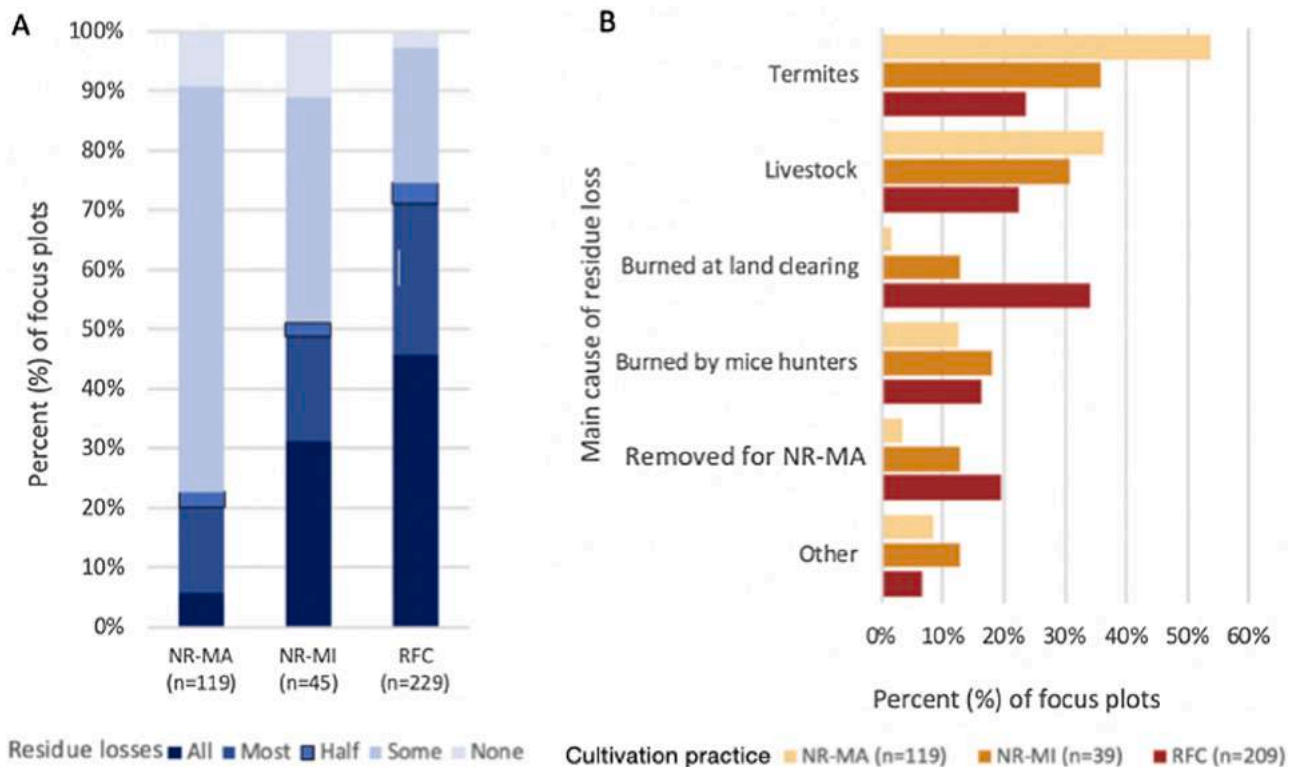


Fig. 5. (A) Extent of residue loss on maize focus plots for Not-Ridged with Mulch Added (NR-MA), Not-Ridged with Mulch In-situ (NR-MI), and Ridge-Furrow Cultivated (RFC) plots. (B) Main causes of residue loss.

plots, they had also been promoted when NR-MA was the common promotion message (e.g. before 2013). As a result, the frequency of herbicide use on NR-MA and NR-MI plots did not differ significantly (Fig. 6). Overall, the majority of NR plots were cultivated without herbicides. Herbicides were, however, used on one quarter of RFC plots, which accounted for a much larger land area than the NR plots. This use was primarily by the better-off households who could afford them (Bouwman et al., 2020). In addition to herbicide use, weeds were also controlled using banking (remaking ridges). Forty-two percent of NR-MI focus plots ($n = 45$) were reported as banked (Fig. 6). By contrast, NR-MA plots were rarely banked. Proportions of NR-MA, NR-MI and RFC plots with herbicides and banking were similar when comparing 3-year CA practicing and neighbouring households.

3.3. The adaptation of CA principle 3: Crop rotation and intercropping

Crop rotation and intercropping constitute the third principle of CA.

Surprisingly, however, in the study area NR was associated with reduced crop rotation. Although maize and groundnuts were the dominant crops, NR land (particularly NR—MA land) was more commonly planted to maize than RFC land (Fig. 7A). As a result, crop rotation occurred far less frequently on NR—MA plots (Fig. 7B). This applied both to CA practicing households and the neighbouring households. Overall, crops were rotated on only 33 % of consecutive (two-year) NR plots and on 74 % of consecutive RFC plots. Thus, CA promotion appears to have resulted in reduced crop rotation. This may be due to a focus on maize in early CA promotion and because of labour requirements considerations. Since maize residues provide the most ground cover, practising NR—MA on a former maize plot may reduce the labour required for adding mulch. Further, although groundnuts had been integrated into the CA demonstration-trials and included in CA promotion messages, many farmers did not appear to like growing groundnuts on NR plots. Some argued that mulching with groundnuts was cumbersome as the mulch has to be removed in order to enable harvesting. Some farmers also

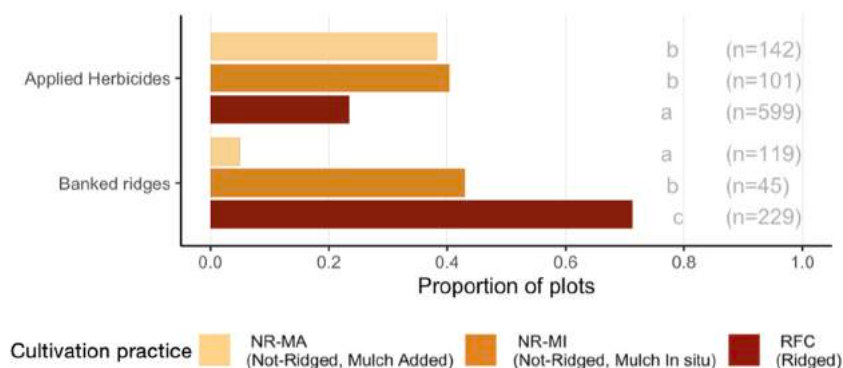


Fig. 6. Weed control strategies in each cultivation practice. Banking involves the remaking of ridges. Estimated proportions account for location as a random effect; those followed by the same letters are not significantly different ($P < 0.05$).

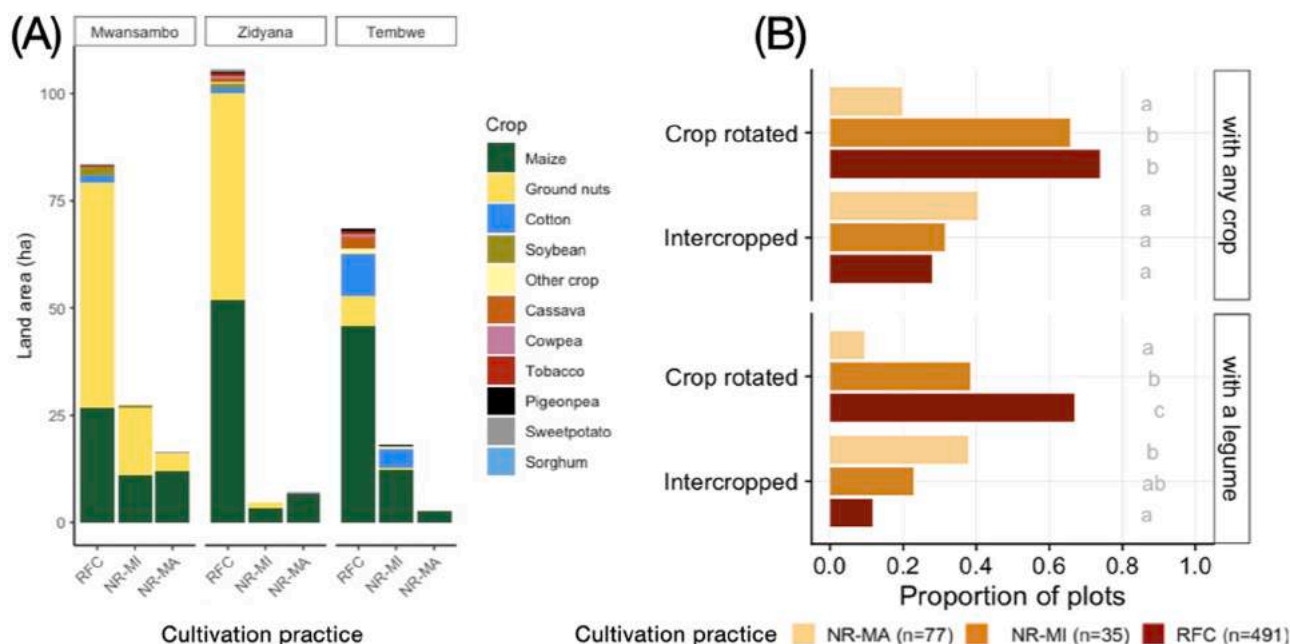


Fig. 7. (A) Crop diversity in area cultivated to different crops for Not-Ridged with Mulch Added (NR-MA) plots, Not-Ridged with Mulch In-situ (NR-MI) plots, and Ridge-Furrow Cultivated (RFC) plots. (B) Estimated proportion of plots rotated and intercropped (with a legume species) in each cultivation practice. Only plots cultivated using the same cultivation practice in 2014/2015 and 2015/16 are considered. Estimates account for location as a random effect; those followed by the same letters are not significantly different ($P < 0.05$).

argued that harvesting groundnuts is easier on loose soils, a point corroborated by Mloza-Banda (2002). Note that loose soils are achieved through tillage (ridging) and that harvesting groundnuts involves significant soil disturbance.

The relative frequent occurrence of intercropping with legumes on NR-MA and NR-MI plot can also be understood as related to CA promotion. CA promoters often provided legume seed for intercropping (e.g. cowpea seed) (Fig. 7B). However, even with the increased intercropping taken into account, crop diversification as a whole (rotation and intercropping combined) was more frequent on RFC plots than on NR plots.

Although land areas dedicated to crops like cotton, tobacco and cassava were limited in the study area, farmers reported that not ridging (NR) in combination with tobacco cultivation is difficult as its nurseries require a substantial amounts of crop residues, leaving little for CA. Meanwhile, practising NR-MA on cotton plots was considered wasteful because it is mandatory to burn cotton residues for disease control.

3.4. Simultaneously practising all three CA principles was rare

CA has three clearly defined principles which *together* are thought to offer yield and environmental benefits. Yet, the three principles of CA were rarely practised together. We estimate that 74–80 % percent of NR land did not fit the three principle-based definition of CA. This was calculated as follows for the *CA practising households*: 67 % of the NR focus plot land cultivated to maize (36 ha) did not match CA principles 1 and 2 (i.e. reportedly had less than 30 % ground cover at planting, was ridged in 2014/2015 or was banked; see also Figure S2). Further, 22 % of the NR area did not match CA principle 3 (i.e. was not crop rotated or intercropped). Taken together, this suggests that only 26 % of NR land in the survey met the definition of CA. Among *neighbouring households* the same method suggests only 20 % of NR land met the definition of CA. This corresponds to 4% of the farmed land in the study area. Thus, despite the relatively high uptake of CA practices such as minimum tillage and crop residue retention, simultaneous practice of the three CA principles was rare.

3.5. Investigating claimed benefits of CA

CA is claimed to lead to labour savings, earlier planting and (therefore) higher yields (NCATF, 2016). Thus, in addition to investigating how farmers had integrated CA principles into their farming practice, we investigated whether the claimed benefits also apply in farmers' fields.

3.5.1. Timing of planting

Contrary to our expectations, NR was accompanied by later, not earlier, planting. Respondents were asked to recall the date when they planted their maize focus plot(s) in the 2015/2016 season. The average planting date for NR-MA, NR-MI and RFC was December 20, 2015 ($n = 93$), December 19, 2015 ($n = 40$) and December 16, 2016 ($n = 184$) respectively. When tested in a linear mixed model with location (three EPAs) and farm as random effects, the differences in planting date between NR-MA and RFC were significant ($p < 0.01$), while the differences between NR-MI and RFC were not ($p < 0.05$). Similarly, the proportion of plots planted after December 31st was also higher for NR-MA than RFC (see Fig. 8B).

Planting delays may be partially explained by late delivery of input support as enumerators reported several cases in which farmers complained of substantial delays in receiving inputs from CA promotion programs for practising NR-MA. However, agronomic factors also played an important role as ridging seems to enable early planting. Most farmers (81 % of 273 households) reported having finished ridging before the rains. When the rains arrive, as one farmer explained, the loosened soil on the ridges absorbs the moisture and allows for immediate planting. The same farmer explained that thick mulch layers absorb water, causing NR-MA plots to require more rainfall for planting – although they also retain water longer. Thick mulch layers may also delay planting as the mulch needs to be pushed aside for planting and rows are not pre-established.

3.5.2. Labour savings

Respondents usually perceived RFC to require more work than NR. Respondents with multiple types of focus plots were asked, 'Which plot was the most work?' The question was followed by the comment: 'Imagine

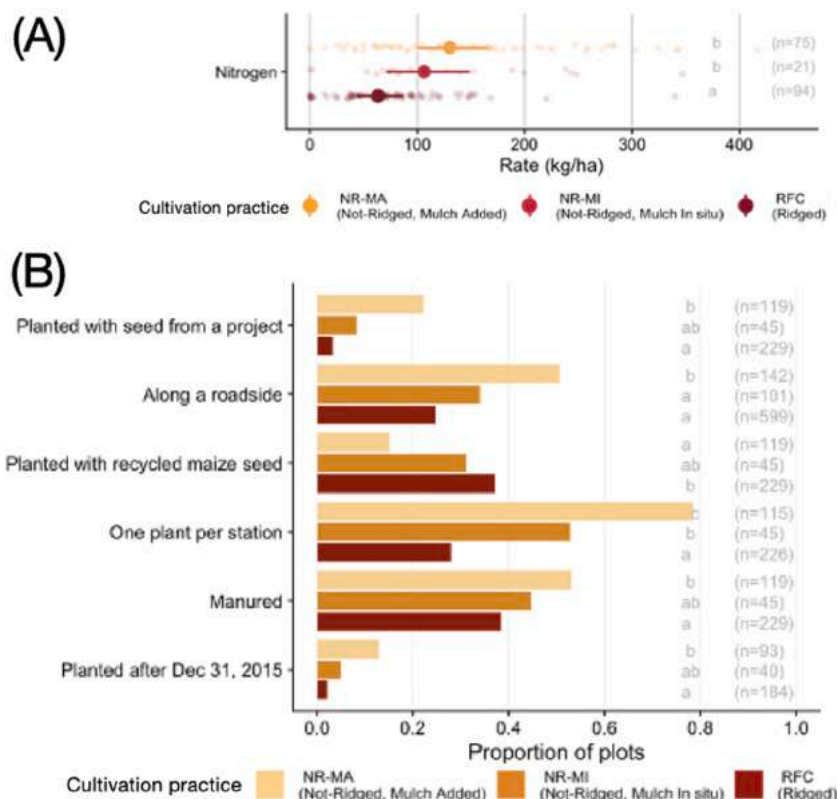


Fig. 8. Investment and management in each cultivation practice. (A) Nitrogen application rates on focus plots by cultivation practice. (B) Estimated proportion of plots, for each cultivation type, planted with seed from a project, along a roadside, planted with recycled seed, planted with one seed per station, manured and planted relatively late. Estimates account for location as a random effect; those followed by the same letters are not significantly different ($P < 0.05$).

they were the same size if there is a size difference.” Respondents with maize plots under NR-MI and RFC consistently reported that their RFC plot required more work ($n = 19$). Similarly, a large majority (91 %) of households with NR-MA and RFC plots reported that the RFC plot took the most work ($n = 86$). More generally, 80 % of farmers ($n = 274$) agreed or strongly agreed with the statement that ‘CA with residues concentrated [i.e. NR-MA] is less work than ridging.’

Before conducting the survey, people involved in CA promotion had described collecting and laying residues as more time consuming than ridging. Survey respondents were therefore asked to report the time required for collecting and laying mulch and the time required for ridging (i.e. the number of working days, the number of people working per day and the number of hours worked per day). Using this information, enumerators calculated the number of six-hour labour days required for mulching and ridging. The mean number of six-hour working days per hectare for mulching in NR-MA was 150.7 (median = 59.3, interquartile range (IQR) = 30.5–131.7, $n = 110$). This was more than 2.5 times the mean number of working days per ha for ridging in RFC which was 58.8 (median = 35.4, IQR = 23.0–59.4, $n = 225$). When the labour data was compared using a linear mixed model with farm as a random effect, these means were significantly different ($p < 0.001$). Thus, despite the farmers’ perception of mulching requiring less labour, it was, on average, reported to require significantly more labour than ridging. The measurements do not include the work involved in guarding crop residues from livestock or mice hunters.

3.5.3. Investments in NR plots

Next to higher labour investments in NR-MA plots, farmers usually also concentrated their farming inputs on NR plots. As Fig. 8B shows, on the NR focus plots (particularly NR-MA) farmers were more likely to use herbicides, better quality maize seeds (i.e. less recycled seed), and higher nutrient input levels (nitrogen fertilizer and manure inputs). The

estimated proportions in Fig. 8B are outcomes of separate generalized linear mixed models in which farm and location are random effects and cultivation type is the fixed effect. Nitrogen (N) rates were on average 1.8 times higher on NR plots (reported at 155 kg/ha) than on RFC plots (reported at 83 kg/ha). When compared in a linear mixed model (again with farm and location as random effects), N rates for NR-MA and NR-MI were significantly higher than in RFC ($P < 0.05$) (Fig. 8A). This result was robust to transformation and outlier removal unlike the results from the P rate estimates which, although they showed a similar trend were not robust to transformation and outlier removal. The model fit for the P rates was poor since many farmers did not apply P-fertilizers.

The higher input rates associated with NR cannot be reduced to differences between NR practising farmers and the rest of the population. For example, farmers with both NR-MA and RFC maize focus plots ($n = 23$) on average applied 168 kg/ha on their NR-MA focus plot and 104 kg/ha on their RFC focus plot. When tested in a paired t-test, the difference was significantly larger than zero ($P < 0.05$) meaning farmers applied more to their NR-MA plots. NR-MA plots were frequently also planted with one plant per planting station (Fig. 8B). This practice has been promoted with CA, especially in a large project by Sasakawa Global 2000 (Ito et al., 2007), and it reportedly requires more fertilizer.

CA in Malawi has had a long history of input support being conditioned on farmers practising minimum tillage or other CA practices (Andersson and D’Souza, 2014). This may have contributed to farmers concentrating their input use on NR plots. Overall, 52 % of NR practising households ($n = 162$) reported to have received input support, separate from Malawi’s Farm Input Subsidy Program, in the previous year. Among farmers who did not practice NR only 6% received such support ($n = 111$). This difference could also be observed at plot level, with NR-MA plots were much more often planted with maize seed provided by a project than RFC plots (see Fig. 8B).

As observed on the satellite images, NR-MA plots were also more

likely to be located along a roadside (Fig. 8B). This ‘roadside bias’ (Chambers, 1983) was largely a response to CA interventions; CA promoters instructed farmers to situate their CA plots along roadsides to ensure the visibility of the farming practice. Although we did not systematically compare all labour investments in focus plots, such public exposure of CA plots is likely to have triggered larger labour investments. Placing one’s CA plot along the roadside may also have been a strategy to obtain input support. In 2016, roadside CA plots had become so common that some villagers complained that they were being excluded from CA interventions (e.g. input support) because they did not have roadside plots. In Tembwe, it was even reported that people had bought land along the roadside so that they could receive input support and demonstrate CA.

3.5.4. Yield returns from NR

Along with higher resource investment, NR plots were also reported to have substantially higher yields. The median (and interquartile range) of the NR-MA, NR-MI and RFC maize focus plot yields were 3.5 Mg/ha (2.2–5.4), 2.6 Mg/ha (1.6–4.3) and 1.5 Mg/ha (0.9–2.2) respectively. These figures are based on the most reliably measured plots (i.e. GPS verified plots with the amount harvested estimated by respondents in 50 kg bags). RFC plot yields reflect typical yields in Malawi. For instance, FAO estimated yields from 2004 to 2014 to average at 1.8 Mg/ha (FAO, 2017).

The yield differences between the three cultivation practices diminished when confounding factors were accounted for. Fig. 9 shows the outputs of linear models and linear mixed models that predict yield. Model A is a linear model with only cultivation system (i.e. the three cultivation practices) as a fixed effect. It shows that NR-MA and NR-MI yields were significantly higher than RFC yields ($p < 0.05$). Models B and C are linear mixed models in which farm and location are random effects. Model C additionally accounts for differences in input use (i.e. nitrogen and phosphate rates, the use of manure, herbicides and of a F1 hybrid) as fixed effects. As shown in Model C, after accounting for input use, differences between NR-MI and RFC were no longer significant ($P = 0.47$).

Running the models on other data subsets (also including plots with only farmer-reported areas, and including oxcart (corrected) measured yield data), while accounting for other practices (e.g. distance from household, number of plants per station and plot history – previous crop and previous cultivation method) as fixed effects, yielded similar results. Yields of the now discouraged NR-MA practice remained significantly different from RFC ($P > 0.05$), but differences between NR-MA and NR-MI plots and NR-MI and RFC plots were often no longer statistically significant (see Supplementary Material, Figure S3). These findings suggest that yields of NR-MA plots were systematically higher than RFC

plots in the 2015/2016 season – even when the NR-MA plot was ridged in the previous year.

Farmers’ motivations for practicing NR-MA and NR-MI mirrored the reported yield data. Higher yields were the most commonly reported motive for practicing NR-MA. It was reported by 87 % of respondents with NR-MA ($n=122$). In contrast, only 27 % of respondents reported higher yields as a motive to practice NR-MI. Instead, labour savings constituted the main motive for practicing NR-MI.

4. Discussion

The common ridge and furrow cultivation (RFC) practice that characterises Malawian agriculture, was introduced by the British colonial administration as a means to combat soil erosion (Beinart, 1984; McCracken, 1982). Praised as a ‘truly remarkable system’, it offers not only erosion control but also weed control and labour savings (Lal, 1990). Ironically, among CA promoting organisations in Malawi, RFC is now considered a major cause of soil erosion (NCATE, 2016). For several decades, interventions have sought to stop the practice of ridging and to convince farmers to adopt minimum tillage, mulching and crop diversification. However, as our results show, most farmers still till the soil when cultivating their crops and do not adopt the CA principles or follow the promoted practices as intended.

Of the farmers who did engage with the promoted practices (a minority), very few actually practised minimum-tillage over consecutive seasons. Instead, they rebuilt ridges (banking) on one-third of the NR plots during the growing season. Farmers also returned more than half of the NR land to ridge-furrow cultivation in the following season (Section 3.1). These observations cast further doubt on estimates of the uptake of CA by smallholder farmers in Africa which tend to be based on the number of farmers practising minimum tillage in one season (Andersson & D’Souza, 2014). This suggests that even the very low uptake rates reported are deceptively high (Brown et al., 2017b).

The area extent of CA uptake was limited because farmers moved crop residues from other plots to their non-ridged plots (Figure 4). Where crop residues were kept *in situ*, 70 % of these plots were bare of ground cover at the beginning of the season when the most erosive rains fall ($n = 23$) (Section 3.2.2). Finally, NR plots showed reduced, rather than increased crop diversification (Fig. 6). Thus, the vast majority of apparent non-ridged plots did not meet the definition of CA (Section 3.4).

Our findings indicate that understanding *how* the component principles of CA are implemented is essential to understand the constraints that farmers face – constraints that are likely to continue to result in poor uptake of CA. These topics are discussed in the following two sections.

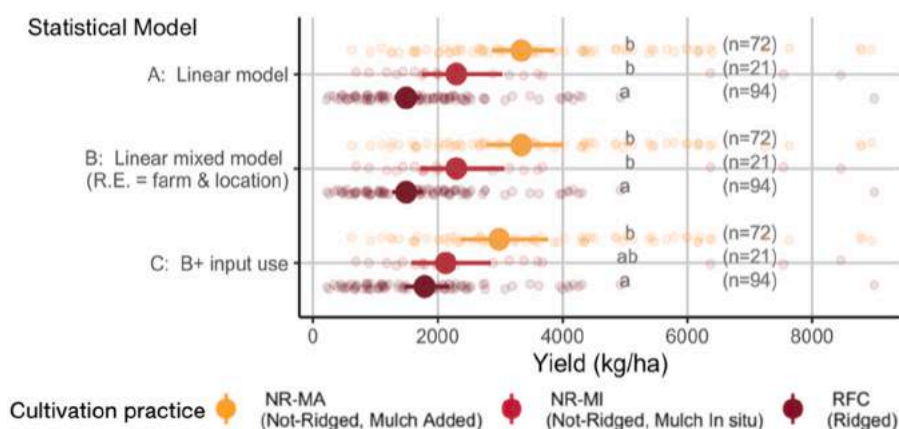


Fig. 9. Estimated yields of the three cultivation practices. The statistical models cumulatively (from A-C) account for sources of confounding. (A) reports raw means. (B) accounts for farm and location (EPA) as random effects. (C) accounts for the random effects of B plus input use (fertilizer, manure, hybrid seed and manure) as fixed effects. For each model, means followed by the same letters are not significantly different ($P < 0.05$).

4.1. The adaptation of conservation agriculture

Our findings resonate with recent critiques of the concept technology adoption that argue that: ‘*Technology packages do not circulate and spread as fixed entities but are changed as they are implemented or re-invented locally*’ (Glover et al., 2019). We found two styles of CA emerged from this process of local re-invention – NR-MA and NR-MI. Below, we elaborate how the emergence of these styles of CA farming can be understood as a convoluted process of adaptation. The styles of CA practised, constitute simultaneously an adaptation to agronomic challenges in farmers’ fields, and to an institutional environment characterised by input-supported technology promotion and oriented towards large-scale adoption.

4.1.1. The practice of NR-MA

The practice of adding mulch to non-ridged fields (NR-MA) reportedly emerged in Mwanambo and Zidyana in the mid-to-late 2000s. CA in Malawi had initially been promoted as non-ridging with mulch *in situ* (NR-MI), but agronomic problems caused by limited ground cover caused a shift. In an early CA project it had been observed that low maize yields and livestock browsing had left ‘*[m]ost of the land bare*’, causing ‘*[i]ncreased incidences of sheet erosion where no ridging was done due to little surface cover*’ (Mataka, 2003). This is of course ironic as the minimum-tillage project aimed to reduce land degradation (Mloza-Banda and Nanthambwe, 2010). The developed response, to collect crop residues from large areas and to concentrate them as a thick layer on the non-ridged plot (NR-MA), offered several advantages: It reduced run-off and erosion, smothered weeds, improved water retention and could thus improve yields. Subsequently, NR-MA was taken up in the on-farm trials in the study area, in demonstration plots of promoting organizations, and even became a requirement for farmers who wanted to receive input support. To facilitate such input (and knowledge) support, as well as to increase the visibility of CA promotion, aspiring CA farmers were instructed to practice NR-MA along roadsides (Fig. 8B).

A combination of agronomic and institutional factors thus resulted in farmers piling crop residues on their CA fields. This adaptation also reinforced an association that had emerged during earlier, input-supported CA promotion in Malawi (Ito et al., 2007); that between crop residues and high input use (Fig. 8). This association is also important for agronomic reasons, as earlier research on CA in southern Africa has shown that ‘*moisture conservation and subsequent yield benefits... [of CA] only became apparent when residue application was combined with fertiliser*’ and, ‘*[a]dequate fertilisation is therefore key to success in CA*’ (Thierfelder et al., 2013c).

Moving large amounts of crop residues involves a lot of work. To achieve 80–100 % ground cover, 8–12 Mg/ha of maize residues are required (Naudin et al., 2012; Vanlauwe et al., 2014). As *in situ* residues tended to dwindle during the dry season and the thickest layers of crop residues observed in the study area far exceeded the amounts needed for 100 % soil cover, it is not surprising that practising NR-MA often ended up requiring more pre-season labour than ridging (Section 3.5.2). Thus, this emergent style of CA annulled the labour savings associated with abandoning ridging by hand hoe.

Next to high labour requirements, the promotion of NR-MA had an unintended impact on crop diversification. As noted by Mloza-Banda and Nanthambwe (2010), CA promotion in Malawi encouraged farmers to intercrop maize with legumes rather than to practice crop rotation. Although maize-legume intercropping increased with the promotion of CA, the emergence of NR-MA was associated with a dramatic reduction in crop rotation (Fig. 6). Farmers predominantly cultivated maize on their NR-MA plots and indicated that the thick mulch layer was not well-suited to crop rotation (Section 3.3). Rather than rotating crops, farmers often rotated their tillage practice; e.g. they did not practice NR in the same spot in consecutive seasons (Section 3.1). Doing so, farmers indicated, enabled crop rotation, prevented the build-up of white grubs in the crop residues (a problem also noted by Thierfelder et al., 2015a),

and served to spread the benefits of CA evenly across the farm.

Although not planned, NR-MA became the dominant style of practising CA (Figure 4). However, the area on which it was practiced remained small due to the lack of crop residues and the time required to gather them.

4.1.2. The practice of NR-MI

As elaborated above, NR-MA emerged as a response to promotional practices and agronomic problems. However, ‘*the need to secure or even import large quantities of crop residues or other biomass for distribution over the field*’ later came to be dismissed by managers of CA promotion. They regarded the piling of crop residues as a ‘*misguided perception, created mainly by field staff*’ which ‘*limited the rate of uptake and area coverage of CA*’ (Bunderson et al., 2017). Subsequently, promotional messages shifted back towards keeping residues *in situ* (NR-MI), as had been the message in the early days of CA promotion. With the return to the NR-MI as CA model to scale, the agronomic benefits of thick residue layers disappeared, and the weed and erosion problems associated with lack of ground cover re-emerged (Section 3.2.2). The resulting weed infestation led many farmers to revert to tillage in their NR-MI plots (Fig. 5).

The old problem of bare soils at planting is likely to persist. To achieve 30 % ground cover – a commonly used threshold in documents on CA – one needs 2–3 Mg/ha of biomass and no losses during the dry season (Erenstein, 2003; Naudin et al., 2012; Vanlauwe et al., 2014). Maize yields in Malawi, including in the study area, are around 1.6–1.8 Mg/ha and residue losses during the dry season are often substantial and unavoidable (Fig. 5). Nevertheless, NR-MI has become the standard in CA promotion in Malawi. As the government’s *Guidelines for implementing Conservation Agriculture in Malawi* outlines, ‘*Keep the message on CA simple: Make small planting holes, retain crop residues and other biomass produced in situ, and diversify crops with rotations, intercrops and/or relay crops.*’ (NCATF, 2016).

Meanwhile, the benefits of CA outlined in the *guidelines* are based on the results of on-farm CA trials that did not evaluate the now promoted NR-MI practice. These trials have much higher biomass production (often 4–6 Mg/ha) than most farmers achieve (Ngwira et al., 2013; TerAvest et al., 2015; Thierfelder et al., 2015a). Further, in the study area, many of the on-farm trials had mulch added to the CA treatments and may thus be considered as resembling more the practice of NR-MA than NR-MI. Hence, despite many years of on-farm research into CA in Malawi, current CA policy – which promotes ‘*keep mulch in situ*’ – lacks an evidence base.

Although the style of CA that is currently promoted, NR-MI, is (potentially) more scalable than the locally emerged style of CA which requires large amounts of crop residues (NR-MA), there is scant evidence that NR-MI provides yield benefits in farmers’ fields. The two styles of CA practised by farmers thus represent a trade-off between yield and environmental benefits (in NR-MA) and the technology’s scalability (in NR-MI).

4.2. Environmental, farm productivity and labour impacts of the emergent CA practices

In view of the limited uptake by smallholder farmers, recent research on CA stresses the need for adaption to local circumstances (Brown et al., 2018a; Thierfelder et al., 2016). A focus on the (likely) impacts of local adaptations of CA is thus warranted. We turn to these below.

4.2.1. Residue retention and carbon stocks

yet CA interventions appear to have resulted in reduced crop residue burning, yet it is not evident that this will result in increased soil organic matter (SOM) or carbon sequestration. A meta-analysis did not find meaningful increases in carbon stocks due to CA in southern Africa (Cheesman et al., 2016). On-farm CA studies in Malawi found no differences in soil carbon when measured at sufficient depth to account for stratification – i.e. 30 cm or more (see Luo et al. (2010)) – even when

large amounts of crop residues were retained or added (Ngwira et al., 2012; Thierfelder et al., 2013b). Even if SOM build-up could be stimulated by increasing the rates of crop residue addition any benefits would be at the expense of locations where residues are removed.

4.2.2. Soil erosion

Although a major aim of CA promotion it appears the impact on soil erosion was minimal. Indeed, the promotion of NR-MI may have increased erosion as this style of CA was often associated with bare ground. Although both mulching and ridging have been shown to be capable of reducing erosion (Giller et al., 2009; Mughogho, 1998), there is scant evidence that CA reduces soil erosion any better than ridging – a practice also introduced (and imposed) to slow down and reduce run-off (Beinart, 1984; McCracken, 1982). While many studies have measured water infiltration in on-farm trials in Malawi (Ngwira et al., 2013; TerAvest et al., 2015; Thierfelder et al., 2013a) and used to show the anti-erosion benefits of CA, the capacity of ridges to hold water and slow run-off has been neglected. These studies are therefore not informative of plot-level run-off or erosion.

Concerns over soil erosion constituted a major driver of CA interventions in the Nkhotakota district. Possibly such concerns were informed by observations of the Chia lagoon that annually becomes turbid during the rainy season, due to sediment transported from the Lifuliza River. Such concerns do not appear to have shaped farmers' CA practices much. Farmers recognized the value of reducing soil erosion, and saw ridging as a method of doing so – as a remark of a Mwanambo farmer illustrates, 'The field is on a steep slope and [therefore] cannot do without ridges.' Yet, their shifting of CA plots within the landscape and their concentrating of CA plots along roadsides suggests that considerations other than soil erosion informed their choice of CA plot location (see Section 3.1 and Fig. 8).

4.2.3. Yields and farm productivity

As discussed above, we found that the now discouraged NR-MA practice had significantly higher yields than RFC, even when corrected for a number of confounding factors, and when plot been ridged in the previous season. This latter finding is remarkable as it contrasts with the received wisdom that yield benefits of CA only accrue with the number of years CA is practised (Rusinamhodzi et al., 2011; Ngwira et al., 2014a; Thierfelder et al., 2013b, 2015b). Nevertheless, the found yield benefits of NR-MA over RFC should be treated with caution. First, because our yield findings only include one season. Second, our yield findings are based on farmer reported yields rather than direct measurement and may therefore be biased (enumerators believed some farmers exaggerated NR-MA plot yields). Third, it is also possible that the observed yield differences are caused by differences in management practices that were not measured – or by a re-allocation of labour investments from RFC to NR-MA plots.

NR-MI plots also yielded significantly more than RFC plots. However, when we corrected for input rates, the differences were no longer significant for the most reliable yield data subsets (GPS verified plot sizes). This is in accordance with CA research in the region that has shown that no-tillage without crop residues does not increase yields – in fact it often substantially reduces yields (Ngwira et al., 2014b; Thierfelder et al., 2013c).

Shifting the perspective from the plot to the farm level, the impact of CA practices on farm productivity appears to be minimal. With NR-MA typically only covering 13 % of the farm area of farms with NR-MA plots, even a 90 % increase in yields with NR-MA results in only a 12 % increase in farm productivity. To find that CA did not substantially affect farm productivity matches results of Mango et al. (2017) who reported no significant impact of conservation agriculture adoption on the Food Consumption Score of farmers in Malawi and Zimbabwe.

4.2.4. Labour requirements, weed control and planting timing

Studies of the impacts of CA on labour have provided varying results.

For instance, Montt and Luu (2019) report that across SSA, CA increases total labour requirements. A meta-analysis by Dahlin and Rusinamhodzi (2019) found that whereas CA without herbicides increases total labour requirements, CA with herbicides reduces them. They also report that the yield returns to labour for ridging are similar or better than those for CA with herbicides. On-farm trials in Malawi, however, report that CA with herbicides saves labour in comparison to ridging (Ngwira et al., 2012).

Our results also suggest that the labour impacts of CA are not straightforward. Most respondents perceived NR-MI and NRM-A to require less work than RFC (Section 3.5.2). The exertion required for ridging likely plays a role in this perception. However, the reported pre-season labour requirements were significantly greater for NR-MA than RFC. This finding corresponds with Chinseu et al. (2018) who recorded comments of farmers who abandoned CA. These farmers argued that CA was more hassle than RFC due to the work involved in securing, distributing and guarding crop residues. Assessing the impacts on labour is thus complicated, not only because CA changes the nature of farm work, but also shifts labour requirements in time. As was apparent in our findings, NR-MA required lots of labour in the dry season for crop residue collection and placement. Yet, since thick (i.e. 6–10 Mg/ha) layers of crop residues smother weeds (Gill et al., 1992; Ngwira et al., 2014b; Twomlow et al., 2008), this eases labour demand during the growing season (Wodon and Beegle, 2006). In contrast, with less than 3 Mg/ha of biomass, weed suppression is likely to be negligible (Gill et al., 1992; Ngwira et al., 2014b; Twomlow et al., 2008). NR-MI thus increases labour requirements for weeding during the growing season.

Acknowledging the complications of assessing CA impacts on labour, it is however clear that predictions emanating from measurements in on-farm trial plots are of little use as they have little bearing on farmers' situations. First, the labour requirements for residue collection (and storage) is typically unaccounted for in plot-level based predictions. Second, with herbicides being applied on 25 % of the RFC plots and 44 % of the NR plots, the comparison of CA *with herbicides* to RFC *without herbicides* rarely applies. Instead, herbicide promotion with CA appears to have contributed to the better-off substituting the labour they hire with herbicides thus contributing to the food insecurity of the worse-off (Bouwman et al., 2020).

5. Conclusion

Numerous studies have sought to understand why African smallholders are not adopting CA (Brown et al., 2017, 2018b; Chinseu et al., 2018; Hermans et al., 2020). Studying situations of low uptake, these studies often report that farmers are not convinced of the merits of CA, and that it is unsuitable for their situation. We took a different approach. By deliberately focusing on an area where CA has been intensively promoted and where relatively high farmer uptake had been reported, we sought to understand the ways in which Malawian farmers integrated CA practices on their farms. Overall, we found that the CA principles were rarely practised as intended and may even have adverse environmental impacts due to a lack of ground cover. Farmers collected residues from large areas and piled them to create a thick mulch layer in their CA fields, mimicking what they had seen in demonstration plots. Rather than maintaining reduced tillage plots in the same fields, the farmers shifted them from field to field, to spread the potential benefits of mulch. The use of intercropping or crop rotation was significantly reduced when farmers retained mulch in their fields. As a result, the uptake of all CA principles together, was very limited.

In response to an emergent style of CA that concentrates crop residues, the CA promotion message has now come full circle. Farmers are now instructed to keep crop residues *in situ*, which may be more scalable, but results in limited ground cover, weed control problems, increased soil erosion and broken promises of yield improvements. Considering this trade-off, there is no reason to argue that CA provides a 'Compelling story [to] positively transform Malawian agriculture' (NCATF, 2016). A

third decade of CA promotion seems unlikely to promise such a future.

Studies that seek to understand the poor uptake of the technology by farmers in sub-Saharan Africa often focus on the institutional environment in which CA is promoted. Proposed ‘fixes’ often include better technical support for farmers, and more participatory and inclusive extension approaches. Thus, the relevance of on-farm experiments to farmers’ circumstances remains unquestioned. By contrast, our results suggest that the reason for the lack of CA adoption lies with the technology itself. In line with Giller et al. (2015), we call for a paradigm shift in the responses to the poor performance of CA in Malawi. Going beyond attempts to improve CA promotional practices and fitting CA principles to farmers realities, agricultural research and intervention could perhaps better strive to understand what farmers are doing and aim to help them do it better. For instance, in the context of the present study on CA related farming practices, it would be worthwhile to investigate the exceptional popularity of groundnut production, and how the integration of legumes (through rotation and/or intercropping) might be improved and expanded – rather than continuing to devote scarce resources to the promotion of conservation agriculture.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.agee.2020.107224>.

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