

## Article

# Meta-Analysis Approach to Assess the Effects of Soil Tillage and Fertilization Source under Different Cropping Systems

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**Abstract:** Crop yield under reduced tillage (RT) practices is a concern for sustainable production worldwide because it is related to different environmental and agronomic factors than conventionally tilled soils. This study aimed to evaluate how climate, soil, and farming practices could affect crop yield under RT, especially under different sources of fertilisation [mineral (M), mineral + organic (MO), and organic (O)]. Multilevel meta-analysis was adopted. The analysis was performed taking into consideration environmental conditions, soil properties, crop rotation, and crop species. Only studies that reported the interaction effect of soil tillage and nutrients management on grain yield were included. The results suggest that the impact of soil tillage and fertilisation sources on crop yield depended on crop species. Using reduced tillage practices, adopting only organic nutrient sources could produce enough grains for legume crops. However, combining both inorganic and organic fertilizers added benefits for cereal crops in terms of grain yield production. This study highlights how conservation tillage practices could be affected by environmental and agronomic factors.

**Keywords:** conservation agriculture; reduced tillage; low-cost alternative nutrient managements inorganic and organic nutrients sources; sustainable agriculture



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## 1. Introduction

In the last decades, the transformation to industrial society determined changes in agricultural practices from their basic function of providing food and labour to becoming a supplier of raw materials in agro-industrial and agri-business systems. However, the industrial agriculture system is heavily dependent on fossil fuels and synthetic agrochemicals as the main source of energy and material to manage the cultivated plant in the agro-ecosystems [1]. In addition, it is managed by large-scale monoculture and cultivation based on intensive soil tillage operations. The adoption of mouldboard plow is considered part of farming practices needed for seedbed preparation. It represents the main method of crop establishment for centuries that contributes to the evolution of agriculture and food production [2]. Indeed, plow-based tillage methods modified the soils' physical, mechanical, and biological properties and contributed to providing various benefits and services, including favourable soil structure for seeds and seedlings, pest control (weeds, insects, and diseases), improving soil aeration, and incorporation of crop residues and fertilizers [3,4]. It has always been considered an important technological development that is regularly placed at the beginning of each crop cultivation. Despite the benefits mentioned above, it has been observed that conventional tillage practices resulted in harmful consequences to the natural resources and environmental health [5,6]. Indeed, soil compaction as a form of soil degradation, mainly caused by heavy machinery's weight and frequent use, leads to poor water infiltration, limited root growth, and consequently negative impacts on crop production. Intensive tillage regimes degrade soil fertility by increasing soil organic matter

oxidation and soil erosion [7]. Moreover, the environmental impact of traditional agriculture, mainly based on intensive tillage and mono-cropping, is high when considering soil and water deterioration [8]. Based on these constraints, it has become commonplace to consider primary tillage practices, such as plowing, as an agronomical practice that should be reduced as much as possible to preserve soil fertility and productivity. Therefore, there is an urgent need to satisfy the growing human population's food demand through agricultural practices based on sustainable land management [8–10].

Nowadays, conservation agriculture practices based on reduced tillage, cover cropping, and crop rotation are widely adopted because they represent a way to practise agriculture that leaves minimum damage to the environment while maintaining crop yield. Thus, they are fundamental for planning sustainable farming systems [10], and involving such practices may result in improved agro-ecological services that maximise productivity and profits and minimise environmental damage. Conservation tillage that includes reduced or minimum tillage (RT), mulch tillage, ridge tillage, and no-tillage systems is gradually becoming attractive to farmers. This is because it saves labour and fuel costs, as plowing is the most energy-demanding process in the production of arable crops [11]. Different studies have stated that agricultural systems based on reduced mechanical soil disturbance represent a suitable alternative to conventional tillage (CT) regarding their impact on soil and the environment [7,10,12]. In comparison with CT, reduced tillage practices determine lower macro-aggregate destruction, hence reducing the exposure of soil organic matter to mineralisation [3]. Conservation tillage systems significantly decrease greenhouse gas emissions [13–15]. Moreover, conservation management improves soil health and quality [5], enhanced soil physical properties [16], increased soil microbial biomass [17,18], and positively affected soil aggregation [19].

In addition to land management practices, agricultural production worldwide is largely based on less efficient off-farm nutrient sources. The use of mineral fertilizer is expected to increase from about 140 million tonnes in 2003 to 200 million tonnes in 2030 [11]. Currently, the application of mineral fertilizers, especially nitrogenous fertilizers, are extensively adopted to ensure the highest crop productivity, even if their application led to expensive and dangerous circumstances for the environment and human health [20]. As commonly adopted under industrial agriculture, the massive and misuse use of mineral fertilizers resulted in land degradation and impairing the sustainability of many agro-ecosystems. This is mainly because of the large amount of fossil energy required for their manufacturing and field application which significantly affect greenhouse gas emissions (GHGs) [21]. The development of agricultural practices that can efficiently use nutrients could address these problems and achieve high crop yield with reduced impact on the environment [20]. Regarding environment and soil health, a sustainable and environmentally friendly practice could be the replacement of chemical or inorganic (M) fertilisation with other substitutes, such as mixed inorganic/organic (MO) or sole organic (O) fertilizers. The use of organic sources of nutrients is considered a suitable strategy for matching the production of safe and healthy foods and enhancing the restoration of soil fertility while mitigating the negative effects of climate change [22]. Indeed, the recycling of organic wastes through a circular economy approach contributes to more sustainable agro-ecosystems. These wastes supply a large pool of mineral nutrients by decomposition process mediated to soil microorganisms that can be effectively used for crop production [23]. Under organic fertilisation management, enhanced soil nutrient availability [24] and improved soil quality [25] have been reported. In addition, Wu et al. [26] suggested that using organic nutrient sources can be an effective practice to restore microbial biomass loss due to the intensive application of chemical fertilizers. Finally, they can play a positive part in climate change mitigation by soil carbon sequestration [24].

Despite all the potential and multiple advantages of these alternative soil tillage and fertilisation management for sustainable agriculture systems to improve soil quality and the environment, the yield gap is still a controversial subject. The yield reduction under conservation tillage systems RT and NT, in comparison with conventional tillage

CT, has often been reported [27]. This negative impact of conservation tillage systems can be reduced under certain farming management and environmental conditions. For example, Pittelkow et al. [28] reported that conservation tillage practices along with residue incorporation and crop diversification significantly increased rainfed crop productivity in dry conditions. Correct fertilisation management should be considered a key aspect of conservation agriculture to sustain crop production [29–31]. In addition, Vanlauwe et al. [29] even suggested a proper use of fertilizer as a fourth principle for conservation agriculture, and Lundy et al. [32] highlighted the significance of fertilisation management on reducing the negative impact of conservation tillage systems on crop yield, particularly in tropical and subtropical climate conditions.

The productivity of reduced tillage systems is strongly related to several interacting factors (climatic conditions, soil characteristics, other agricultural practices) that contribute to uncertainty regarding the potential of these sustainable practices to increase agricultural productivity. Su et al. [33] state that it is fundamental to upload and report findings from recent experiments by also including climatic, soil, and agronomical characteristics to reduce this gap. Overall, understanding the effects of using different soil tillage intensities combined with various nutrient sources would help develop farming strategies to optimize crop yield while maintaining sustainability. In this study, a meta-analysis approach has been carried out to summarize the results of independent studies to evaluate the direction and magnitude of tillage intensities effect sizes under different fertilisation management. The main objective of this study was to compare the conservation tillage practice (RT) with conventional tillage (CT) under inorganic (M), organic (O), or mixed inorganic + organic (MO) fertilizers and finally identify under which combination of farming management could lead to increased grain yield productivity.

## 2. Methodology

### 2.1. Study Selection and Eligibility Criteria

An extensive review of the literature that compared crop yields of reduced tillage (RT) and conventional tillage (CT) practices was carried out. As a primary criterion, only studies that compared the effect of RT vs. CT under different fertilisation sources were included. Mineral (M), organic (O), and/or combined M + O (MO) nutrients management were considered. The search was performed using Web of Science, Scopus, and Google Scholar, and studies were assembled with a cut-off date of November 2020. The keywords used for searching the peer-reviewed manuscripts were: (1) conventional or traditional tillage; (2) low, minimum, or reduced tillage; (3) mineral or inorganic fertilizer; (4) organic fertilizer; (5) combined inorganic and organic fertilizers. Then, the appropriate studies were selected using the following criteria: (i) studies must be conducted under field experimental conditions, (ii) the effect of tillage practices under different fertilisation sources on crop grain production, or lint yield in the case of cotton, must be reported, and finally, (iii) treatments must have received the same farming managements and carried out at the same location. Different field experiments (studies) within publications were checked, and grain yield data were separately recorded for each study. One publication can have multiple studies, i.e., the same crop studied over multiple years, the same crop at different sites, or different crop species.

### 2.2. Data Collection

According to the above criteria, 22 publications were assembled and recorded 470 crop yield pair observations (multiple observations within individual studies). These observations were from 42 studies, covered 11 countries which represented 5 continents (Africa, Asia, Europe, North and South Americas) (Table 1). Many selected manuscripts reported data in tables that could be taken directly. Conversely, when data were reported in graphs, they were retrieved using GetData (version 2.26) Graph Digitizer software. Experimental sites represent 7 different climate conditions: tropical, humid subtropical, humid continental, semiarid tropical, Mediterranean, semiarid, and arid climate conditions.

**Table 1.** The detailed information of selected studies and collected data. The data for authors, year, country, crop, soil tillage, and fertilisation sources. CT: conventional tillage, RT: reduced tillage, RT1: reduced tillage 1, RT2: reduced tillage 2, MT: minimum tillage, LT: low tillage, LT1: low tillage 1, LT2: low tillage 2, M: inorganic fertilisation, O: organic fertilisation, MO: mixed inorganic + organic fertilisation; PM: Poultry manure; LGM: Legume green manure; FM: Farmyard manure; VC: Vermicompost; C: Compost; SM: Sheep manure; MSW: Municipal solid waste; CM: Cattle manure; U: Urea; AS: Ammonium sulphate; AN: Ammonium nitrate; CM; Chemical weed control; MM: Mechanical weed control.

ID	Authors	Country	Crop	Tillage Practice	Fertilisation	Organic Fertiliser	Mineral Fertiliser	Weed Management
[34]	Amegashie, 2014	Ghana	Maize	CT, RT	M, O, MO	PM	U	CM
[35]	Blaise, 2011	India	Cotton	CT, RT1, RT2	M, MO	LGM	U	MM
[36]	Busari & Salako, 2013	Nigeria	Maize	CT, MT	M, O, MO	PM	U	MM
[37]	Choulwar et al., 2015	India	Cotton	CT, RT1, RT2	M, O, MO	FM + VC	U	MM + CM
[18]	Elsoury et al., 2015	Egypt	Wheat	CT, MT	M, O, MO	FM + C	U	–
[38]	Kakabouki et al., 2019	Greece	Quinoa	CT, MT	M, O	SM	U	MM
[39]	Kumar et al., 2020	India	Wheat	CT, MT	M, MO	FM + VC	U	MM
[40]	Kumar Yadav et al., 2012	India	Sorghum	CT, RT, MT	M, MO	FM	U	–
[41]	Mohammadi et al., 2013	Iran	Sunflower	CT, MT	M, O, MO	FM + C	U	–
[42]	Montemurro, 2009	Italy	Wheat	CT, MT	M, O, MO	MSW	AS + AN	MM
[43]	Nema et al., 2008	India	Pearl Millet	CT, LT1, LT2	M, O, MO	FM	U	MM
[44]	Nouraein et al., 2020	Iran	Chickpea	CT, RT	M, O	FM	U	MM
[45]	Patil, 2013	India	Sorghum	CT, RT1, RT2	M, O, MO	FM	U	MM
[46]	Pradhan et al., 2020	India	Rice, Lentil	CT, MT	M, O, MO	FM	U	–
[47]	Ramachandrapa et al., 2017	India	Finger millet, Pigeon pea	CT, RT, MT	M, O, MO	FM	U	MM + CM
[1]	Sankar et al., 2013	India	Rice, Lentil, Horse gram, Linseed	CT, LT1, LT2	M, O, MO	FM	U	MM
[48]	Serme et al., 2015	Burkina Faso	Sorghum	CT, MT	M, O, MO	C	U	MM
[49]	Sharma et al., 2015	India	Sorghum, Mung bean	CT, RT	M, O, MO	C	U	MM
[50]	Sheoran et al., 2009	India	Maize, Wheat	CT, RT1, RT2	M, O, MO	C	U	MM
[51]	Shumba et al., 2020	Zimbabwe	Maize	CT, RT	M, MO	CM	AN	MM
[52]	Watts & Allen Torbert, 2011	USA	Maize, Soybean	CT, RT	M, O	PM	AN	CM
[53]	Weill et al., 1989	Canada	Maize	CT, RT	M, O	CM	AN	CM

Where data were not given explicitly in the publication, it was inferred from other information when unavailable, for example, soil texture class from soil taxonomic information or from other papers published from the same experimental site. In some potentially suitable publications, the replications number was not indicated; however, where the yield was reported for five years, the replicates number was considered equal to 1. The yield data was collected as grain yield, except cotton as lint yield (tons per hectare). If different degrees of low tillage treatments were reported, i.e., reduced tillage (RT<sub>1</sub>) and reduced tillage (RT<sub>2</sub>), both treatments were compared to the conventional tillage (CT) for the individual study. If a publication reported results from distinct sites and each had its own properties, such sites were kept separate in our analysis.

The following describing variables were collected: (1) research site coordinates were obtained from the studies when reported or from a search based on the name of the research site; (2) the type and rate of each nutrient source used was recorded for each observation; (3) crop species. Site characteristics were also recorded that might explain variances across studies and were available in most publications such as (4) soil texture, obtained using soil texture calculator from the Natural Resources Conservation Service Soils USDA (<https://www.usda.gov/> (accessed on 7 July 2021)), based on the reported percentage of sand, silt, and clay. If the physical properties of soil were not mentioned, the soil texture in each study was noted. Soil textures then were grouped into three categories: (a) fine (clay, silty clay), (b) medium (silty loam, clay loam, sandy clay loam), or (c) coarse (sandy loam, loamy sand); (5) climate conditions were taken either directly from each paper, or using the online database (<https://en.climate-data.org/> (accessed on 7 July 2021) based on the location of the study site, if not reported. Tropical, humid subtropical, humid continental conditions were considered humid conditions, semiarid tropical and Mediterranean conditions as dry subhumid conditions, while dry conditions were represented by semiarid and arid conditions in this study.

### 2.3. Data Analysis

For this meta-analysis study, crop yield paired observations under different farming management, and environmental conditions were collected. Standard deviation (SD) was estimated as 0.1 times the mean for studies that did not report SD [54]. The analysis was conducted using a multilevel random-effects model, with studies nested within publications, which were further clustered within studies. Crop yield production as a dependent variable was quantified by computing the response ratios (RR) [55] as the effect size (Equation (1)):

$$RR = \frac{X_{RT}}{X_{CT}} \quad (1)$$

where  $X_{RT}$  is the crop yield average for the experimental group RT, and  $X_{CT}$  is the crop yield mean for the control group CT. The statistical analysis was performed using the natural logarithm of the effect size ( $\ln RR$ ), calculated for each observation/study [55]. The variance of the response ratio  $v_i$  was calculated using the equation (Equation (2)):

$$v_i = \frac{SD_{RT}^2}{X_{RT}^2 N_{RT}} + \frac{SD_{CT}^2}{X_{CT}^2 N_{CT}} \quad (2)$$

where the standard deviation  $SD_{RT}$ , the sample size (number of replicates)  $N_{RT}$  for the experimental group, and the standard deviation and the sample size of the outcome in the control group by  $SD_{CT}$  and  $N_{CT}$  are shown, respectively. In addition, we examined potential outliers based on a plot of influence diagnostics outliers [56].

Effect sizes within the meta-analysis were weighted ( $w$ ) using the inverse of the variance ( $v_i$ ) of each individual study ( $i$ ) computed as Hedges et al. [55] (Equation (3)):

$$w = \frac{1}{v_i} \quad (3)$$

Eventually, the weighted mean effect size  $\overline{\ln R}$  was estimated as (Equation (4)):

$$\overline{\ln R} = \frac{\sum (\ln RR \times w_i)}{\sum w_i} \quad (4)$$

The 95% confidence interval (CI) was calculated for the mean effect size (Equation (5)):

$$95\% \text{ CI} = \overline{\ln R} \pm 1.96 \text{ SE}_{\overline{\ln R}} \quad (5)$$

where  $\text{SE}_{\overline{\ln R}}$  is the standard error of  $\overline{\ln R}$  was computed as (Equation (6)):

$$\text{SE}_{\overline{\ln R}} = \sqrt{\frac{1}{\sum w_i}} \quad (6)$$

The percent change in selected variables was computed using the equation (Equation (7)):

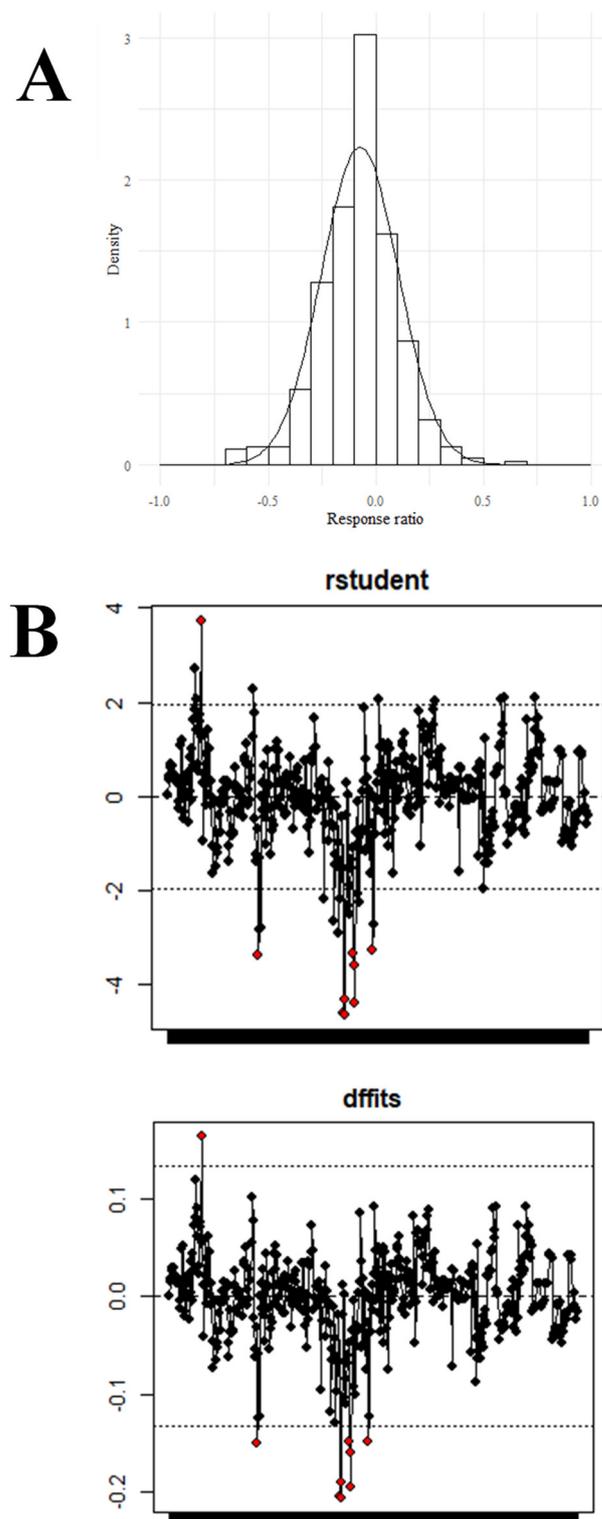
$$(e^{\overline{\ln R}} - 1) \times 100\% \quad (7)$$

Meta-regression analyses were performed to explain the observed heterogeneity between study estimates. The effects of crop species, climate conditions, and soil types were separately included, along with the fertilisation source as covariates in the meta-regression model. A forest plot was used to summarize the effects on grain yield [57]. The meta-analysis was performed using the restricted maximum likelihood estimator (REML) estimation in the *rma.mv* model, together with *escalc* functions of the 'metafor' package [56,58]. All statistical analyses were carried out, and figures were constructed using the R statistical software language [59].

### 3. Results and Discussion

#### 3.1. Data Overview

Yield observations were collected from each study depending on how much information was available. Eventually, we obtained 470 yield pair observations from 22 publications that evaluated the conventional and reduced tillage (CT vs. RT) practices under different agronomical managements and climatological conditions (Table 1). The impact of potential outliers was tested using influential case diagnostics and a variety of influence and outlier analyses (Figure 1), according to Viechtbauer and Cheung [33]. Nutrient sources including mineral or inorganic (M), organic (O), and mixed inorganic + organic fertilizers (MO) were overall well represented. Many observations (more than 90%) were conducted under rainfed conditions, using a rotation cropping system. Several studies have been carried out in different countries worldwide to adopt sustainable agriculture farming by reducing soil tillage intensity (conservation tillage) and reducing mineral chemical fertilisation (using O or MO nutrient sources). In this study, a database representing studies from 11 countries in Africa, Asia, Europe, and North America was attained. However, most of the suitable studies were conducted in India, where twelve different crops were evaluated for yield under all climate conditions. Overall, the data was collected for 16 different crops and seven different soil textures. Maize, sorghum, and wheat are the most studied crops. Other crops such as quinoa, finger millet, horse gram, linseed, mung bean, pigeon pea, soybean, sunflower crop data were also evaluated in this study.



**Figure 1.** (A). Histogram of the effect size represented by the response ratio “RR”. (B). representing influence and outlier analyses. The externally standardized residuals “rstudent” showed study residuals were normally distributed within the two dotted lines. While “dffits” values showed how many standard deviations the predicted average effect for the *i*th study changes after that study is left out.

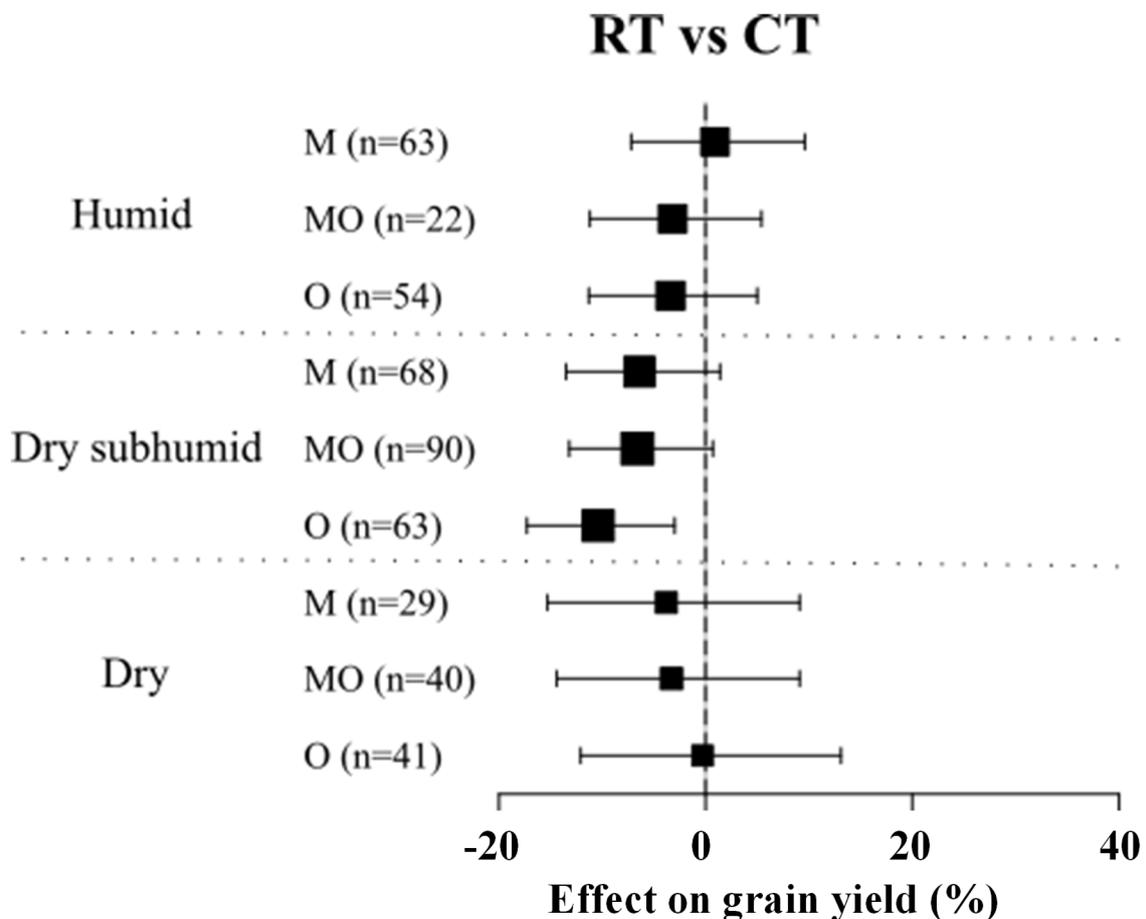
### 3.2. Environmental Conditions

The response of crop yield to reduced tillage (RT) vs. conventional tillage (CT) practices subjected to different nutrient sources [mineral (M), mineral + organic (MO), and organic (O)] under different climate conditions are represented in Figure 2. Results showed that reduced tillage practice performed better under humid conditions, especially when mineral fertilisers are applied, and dry conditions, especially under O fertiliser source, matching the conventional tillage yields overall. A significant negative impact was detected under RT compared with CT, using O fertilisers (−3.8%) in dry sub-humid conditions. There was no significant reduction in grain yields under RT using M or MO fertilizers (Figure 2). The negative effect of conservation tillage practice on crop yield was compensated when using MO rather than O alone in dry sub-humid conditions. These results suggest that using MO under RT practice could increase grain yields under dry subhumid conditions, matching CT. It should be mentioned that all studies conducted under dry sub-humid conditions have reported that CT was found to be superior in attaining higher grain yield for all crops compared with RT. Montemurro [42] reported that using MO sources can reduce yield differences between CT and RT in the Mediterranean conditions, mainly due to the little organic matter content because of the intense mineralisation process than subjected those systems to nutrient loss via leaching with high environmental risks.

Several meta-analysis studies have reported that conservation tillage practices often increase crop yield under dry conditions [27,60]. In agreement with these studies, no significant yield decline under RT compared with CT under dry conditions, regardless of fertiliser sources, was reported in the current study. However, crops grown in drier conditions had more benefits from organic nutrient management [36,61]. This is related to the organic matter that contributes to increased water holding capacity in dry conditions and prevents soil compaction in humid conditions, regarding soil organic matter [62]. More recently, Hijbeek et al. [37] conducted a meta-analysis (based on 20 long-term experiments across Europe) on the effect of using organic nutrient sources on crop yields and observed that organic inputs had more benefits in reduced tillage under humid conditions. Similarly, Wang et al. [63] stated that the addition of organic fertilisers promotes sustainable crop productivity and environmental-friendly soil management of dryland farming. In general, fertiliser management did not affect crop yield under conservation tillage practices in dry and humid conditions.

### 3.3. Soil Properties

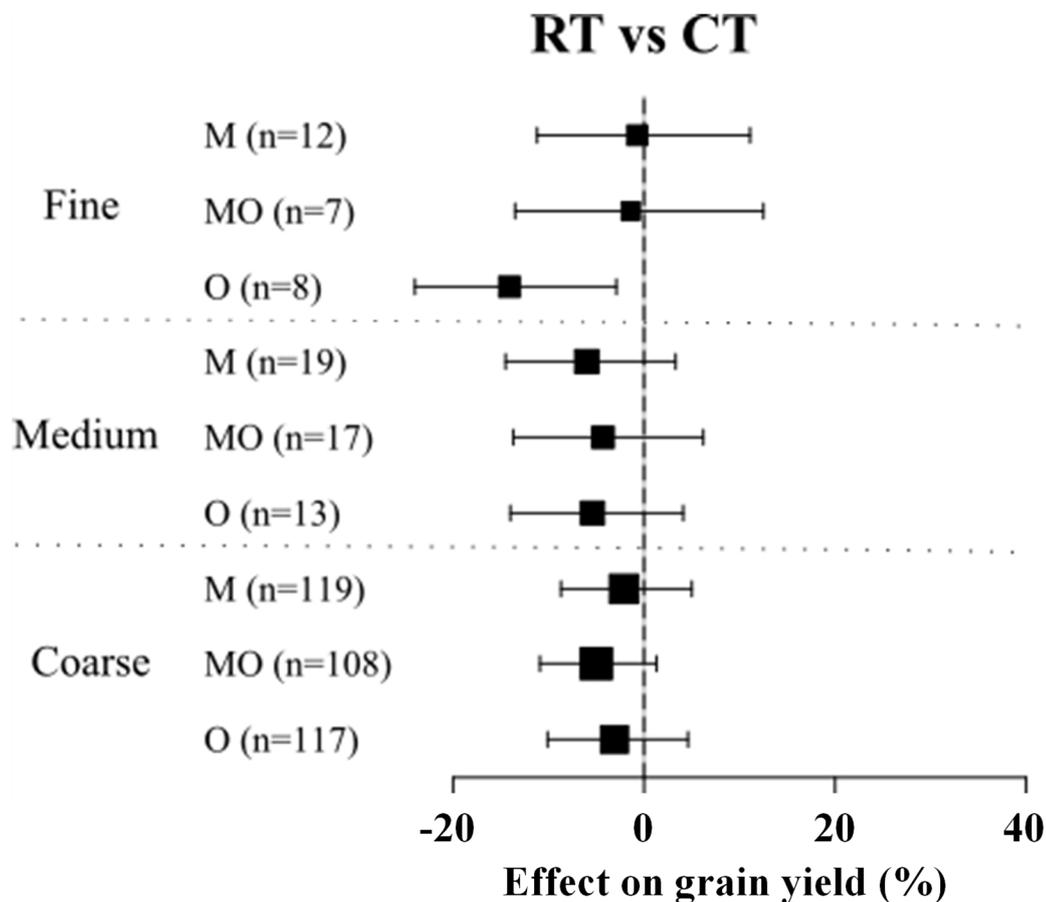
Yield response to reduced tillage (RT) vs. conventional tillage (CT) practices based on different nutrient sources [Mineral (M), Mineral + Organic (MO), and Organic (O)] for different soil textures are reported in Figure 3. Overall, there was a negative trend for crop yield on all soil texture classifications, even if it was not significant. Crop yields on medium and coarse soils under RT were not significantly different from yields under CT, using all fertilisation sources. In comparison with fine soils, O fertilisers alone or combined with M fertilisers under an RT system improved soil structure properties in coarse and medium soils, which leads to considerable yield benefits comparable with CT practice. Rusinamhodzi et al. [64] reported in their meta-analysis a positive impact on grain production under conservation tillage systems on coarse and medium-textured soils and negative on fine soils. Under RT, only on the fine-textured soils, a significant yield reduction was reported when using O fertilizers alone (−14%). This can be attributed to high soil compaction under fine soil using organic fertilizers. Other important factors, such as soil organic carbon, might have a role in these findings [34]. No negative impact was reported under RT using MO fertilizers in fine soils.



**Figure 2.** The response of reduced tillage vs. the conventional tillage practices (RT vs. CT), under different nutrient sources; inorganic (M), organic (O), and inorganic + organic (MO), under different climate conditions, expressed as the average effect on grain yield (%). “n” refers to the number of observations for each subgroup. The vertical line represents the null hypothesis [ $\ln(RR) = 0$ ]. The squares are the point estimate of effect size. The horizontal lines are the associated 95% confidence interval for the population parameter.

### 3.4. Crop Rotation

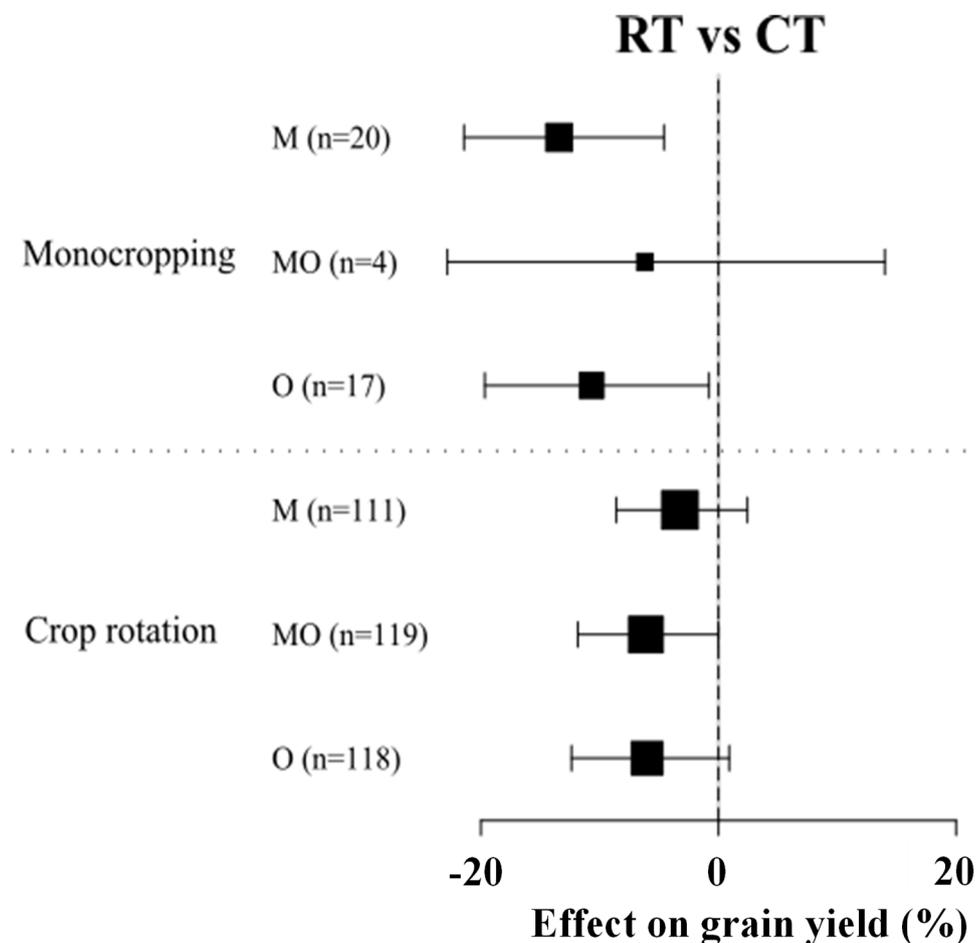
Crop yields under RT were generally like those observed under CT practices under rotation cropping system using all fertiliser sources (Figure 4). Contrarily, significant yield reductions were detected under the monocropping system, especially when using M (−13.4%) and O (−10.7%) fertilisers alone. However, no significant yield reduction was detected under MO’s monocropping system, even if this result is limited due to a small sample size ( $n = 4$ ). In general, crop yield responses to RT compared to CT under crop rotation systems were similar using all fertilisation sources. In accordance with many previous studies, these results indicate the importance of crop rotation for increasing crop yields [17,65,66]. The adoption of systematic rotation could support RT practices by decreasing several biotic and abiotic factors that may threaten crop production. Crop rotation represents one of the most important tools to control weeds [67], to increase N availability [68], and to enhance soil fertility [69] under organic farming approaches. These findings highlight the importance of diversifying cropping systems under conservation tillage practices, such as RT and NT, which have been observed in previous meta-analysis studies [28,47,70,71].



**Figure 3.** The response of reduced tillage vs. the conventional tillage practices (RT vs. CT), under different nutrient sources; inorganic (M), organic (O), and inorganic + organic (MO), under different soil properties, expressed as the average effect on grain yield (%). “n” refers to the number of observations for each subgroup. The vertical line represents the null hypothesis [ $\ln(RR) = 0$ ]. The squares are the point estimate of effect size. The horizontal lines are the associated 95% confidence interval for the population parameter.

### 3.5. Crop Species

Grain yield response to reduced tillage (RT) vs. conventional tillage (CT) practices separated under different nutrient sources [Mineral (M), Mineral + Organic (MO), and Organic (O)] for different crop species are represented in Figure 5. Overall, yield changes under RT management were positive for fiber and oilseed crops at all fertilisation treatments. However, they were not significant. Contrarily, negative yield responses were detected for cereals and legumes under all nutrient sources (Figure 5), with different significance levels. Compared to sustainable nutrient management, no significant reduction was noted for legumes and cereals under RT using M sources. Cereals performed the best under RT when using MO (−3.8%) fertilisers, followed by M alone (−5.4%), matching CT practice. Only significant yield reduction was observed for cereals under RT, using O fertilizers alone (−7%). On the other hand, a significant negative effect for legumes was observed when using MO sources (−14.2%).

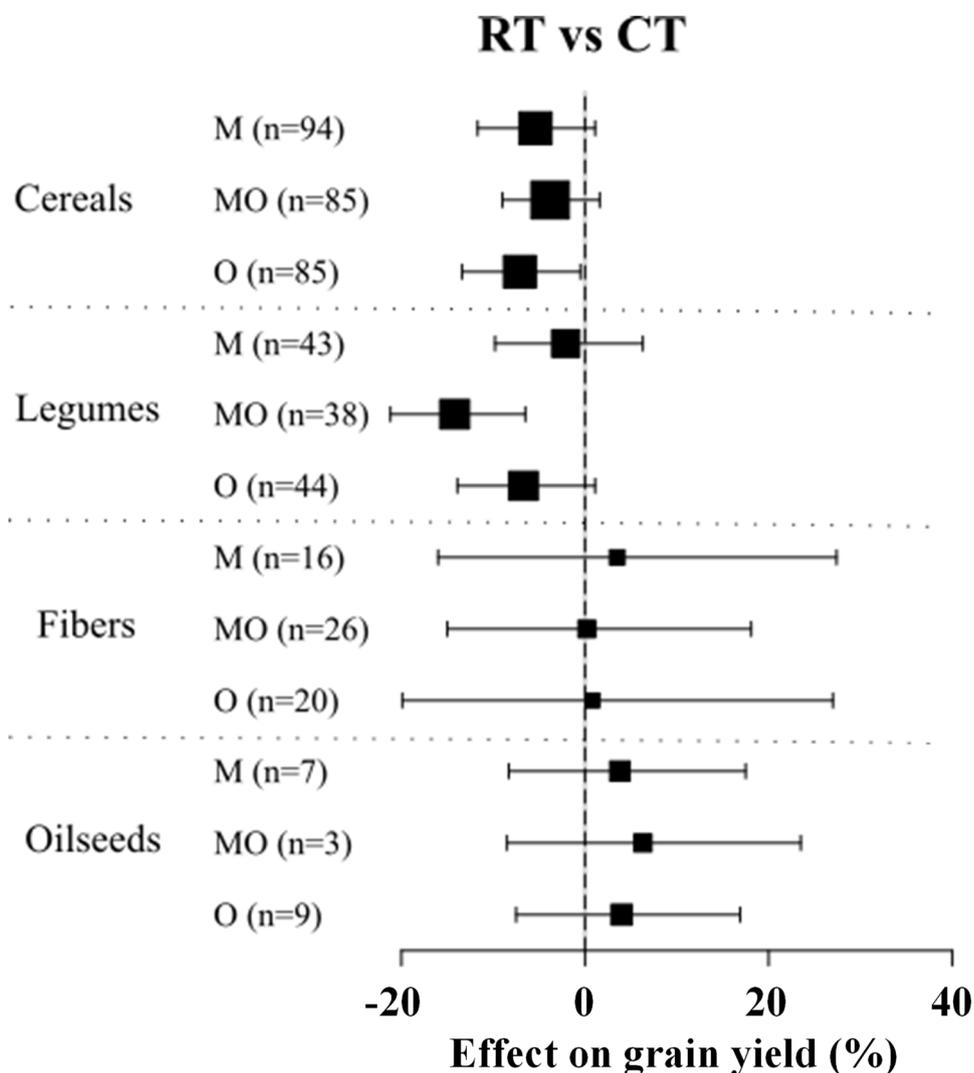


**Figure 4.** The response of reduced tillage vs. the conventional tillage practices (RT vs. CT), under different nutrient sources; inorganic (M), organic (O) and inorganic + organic (MO), for different cropping systems (monoculture vs. rotation) expressed as the average effect on grain yield (%). “n” refers to the number of observations for each subgroup. The vertical line represents the null hypothesis [ $\ln(RR) = 0$ ]. The squares are the point estimate of effect size. The horizontal lines are the associated 95% confidence interval for the population parameter.

These differences may be attributed to different N demands of crop species. They might also be due to the sensitivity of organic fertilisers, subjected to mineralisation process and weather conditions [14,72]. No significant differences support this were reported using M fertilisers for both cereals and legumes under RT. Moreover, it is expected that under different tillage systems, temporally different N mineralisation would occur. Using O sources alone under RT was not enough for cereals’ N needs, which significantly negatively impacted grain production [45]. Comparing the impact of RT vs. CT under organic managements, Campiglia et al. [73] reported that cereals had higher yield under CT due to improved N mineralisation in spring in plowed soils. Greater grain yield for cereals using MO was found, confirming the need to use supplementary N inorganic sources under RT systems [41,42]. Interestingly, twelve out of 16 articles reported that cereals performed the best using MO compared with M or O alone regardless of the tillage system.

The combined application of mineral (M) and organic (O) fertilisers has recently gained much attention as a sustainable farming practice. Several meta-analysis studies have been conducted to compare the effect of various nutrient sources, including MO as potential source, on crop production. A meta-analysis study for 32 long-term experiments highlighted that applying together M and O nutrient sources led to increased cereals yield compared to M or O fertilizers alone [74]. In agreement with the results of this study, they also reported yield benefits for cereals in the following order: MO > M > O. These results

were later confirmed, and increased soil organic carbon (SOC) with MO application was reported [35,75,76]. The same findings also were reported for maize crops in sub-Saharan Africa [77], and they relied on greater yield responses due to extra N added through MO nutrient source. However, for legumes, relying only on organic sources under a reduced tillage system led to no significant differences matching the inorganic fertilizers [44]. These results agree with another meta-analysis study that revealed that yields of legume crops were the least affected by reducing tillage intensities in organic farming [78]. Therefore, the results of this study suggest that under conservation tillage systems such as reduced tillage, depending only on organic nutrient sources, could produce enough grains for legume crops. However, combining both inorganic and organic fertilizers added benefits for cereal crops in terms of grain yield production.



**Figure 5.** The response of reduced tillage vs. the conventional tillage practices (RT vs. CT), under different nutrient sources; inorganic (M), organic (O) and inorganic + organic (MO), for different crop species, expressed as the average effect on grain yield (%). “n” refers to the number of observations for each subgroup. The vertical line represents the null hypothesis [ $\ln(RR) = 0$ ], the squares are the point estimate of effect size, and the horizontal lines are the associated 95% confidence interval for the population parameter.

#### 4. Conclusions

This study provides useful information on the effects of using conservation tillage practices and nutrients management for different crop species under several environmental and soil properties. The results highlighted the importance of environmental and agronomical factors and how their understanding could affect the impact of conservation tillage on crop yield by adopting environmentally-friendly fertilisation sources, such as the total or partial substitution of minerals with organic fertilizers.

The following points can be concluded from the results of this study:

1. Environmental and agronomic factors can lead to yield variability under conservation tillage systems.
2. The impact of soil tillage and fertilisation management on crop yield depended on crop species.
3. The observed yield reduction was mainly pronounced in dry sub-humid regions, particularly when using organic sources alone. However, under these conditions, using MO source with RT system matched CT in grain yield production.
4. Although there was not so much variability under different soil properties, O fertilizers alone or combined with M fertilizers under RT system improved soil structure properties in coarse and medium soils, leading to considerable yield benefits.
5. No negative impact was reported under RT using MO fertilizers in fine soils, represented by clay and silt clay soils in this study.
6. Crop yields under RT were generally like that observed under CT practices under rotation cropping system using all fertilizer sources.
7. Application of only organic nutrient sources (O) under RT system could produce enough grains for legume crops. Conversely, combining both inorganic and organic fertilizers (MO) benefits cereal crops in terms of grain yield production.

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