
Glyphosate-based herbicides on weeds management and maize performance under conservation agriculture practices in eastern Kenya

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Abstract: A three-season research study was conducted at Embu Agricultural Research Station farm to determine the effect of glyphosate-based herbicides on weeds management and maize (*Zea mays L.*) performance under zero-tillage conservation agriculture practice. Glyphosate herbicide sprays were prepared from Roundup Turbo product at the rate of 2.5 L ha⁻¹ and Roundup Weathermax at 1.5, 2.5 and 3.0 L ha⁻¹ rates. Significant ($p \leq 0.05$) differences in weeds management were observed under the tested rate of Roundup Turbo compared to un-weeded control plots. The average grain yield from conventionally tilled plots was 3.6 t ha⁻¹. This did not differ significantly from those of herbicide-managed plots. Low-grain yield (0.1 t ha⁻¹) was observed

from un-weeded plots compared to those from zero-tilled plots that had also exhibited significantly ($p \leq 0.05$) higher net-benefits. The study concluded that the application of herbicides improves weeds control and maize performance.

Keywords: zero tillage; conventional tillage; glyphosate herbicide; weed control; maize performance; net-benefits; agricultural resources.

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1 Introduction

Maize is the most important staple food crop for over 90% of the Kenyan population, where the crop is mainly grown by smallholder farmers who are approximately 75% of the total population (Muui et al., 2007). The crop is mainly grown for its grains, stovers are fed to livestock and empty cobs used as a source of fuel for cooking. Demand for maize grains has continued to rise over the years while per capita grain production has lagged behind the annual population demand (Kimaru et al., 2012; Mutegi et al., 2012a). Weeds competition with the crop for growth resources is singled out as one of the challenges faced by smallholder farmers and therefore limiting the crop production (Terry and Michieka, 1987). In the region, the deleterious effect of weeds is mostly

managed conventionally using hand tools such as jembes and pangas (Berca, 2004). Conventional (CVT) weeding method is constrained by limited labour and weeds that are difficult to manage due to their great diversity in terms of species and nutrient scavenging systems (Mutegi et al., 2012b). Competition for labour during the peak weeding period affects maize production (Waithaka et al., 2006). Over 80% of the farm labour is provided from family members and utilised for higher income-generating enterprises such as coffee, tea and cattle rearing (Ouma et al., 1999).

In a socio-economic study on adoption of herbicide technologies in maize-based cropping systems in central Kenya, Muriithi et al. (1999) recognised that the use of herbicides is the most economical method for weeds control in maize production systems. Similarly, Muthamia et al. (2004) in their studies on conservation agriculture (CA) tillage systems in Kenya reported that the farmers have their farm benefits increased by managing weeds using herbicides. This calls for enhanced research on testing and promoting appropriate herbicides. It was therefore on this basis that a study was conducted to determine the effects of glyphosate-based herbicide products on weeds management and maize performance under CVT and zero tillage (ZT), a CA tillage practice in humid areas of eastern Kenya.

2 Materials and methods

2.1 Site

The study was conducted at the Kenya Agricultural Research Institute (KARI – Embu) farm on the eastern slopes of Mt. Kenya at 00°33.18'S; 037°53.27'E; 1420 m asl and in the upper midlands (UM₃) zone (Figure 1). The region experiences 1250 mm average annual bimodal rainfall and warm temperatures ranging from 21 to 28°C and 16 to 21°C mean maximum and minimum, respectively (Jaetzold et al., 2007). The two rainy seasons are: the long rains (LR) lasting from March to August and the short rains (SR) from October to January (Jaetzold et al., 2007). About 65% of the rains come during the LR and in some years end in July–August with scanty showers (Micheni et al., 2011). The eastern Kenya soils are dominated by humic nitosols (Jaetzold et al., 2007). These are soils of moderate to high inherent fertility due to their high minerals, water and cation exchange capacity levels (Gitari and Friesen, 2001). However, over the years the fertility has declined due to inappropriate soil management and nutrients depletion (Ngetich et al., 2012). Such soils have their physical and chemical properties modified by cropping frequency, nutrients application and residue return (Micheni et al., 2013). The area farming system is mainly of dairying and growing medium maturity maize and field bean (Ouma et al., 1999; Micheni et al., 2003).

2.2 Experimental design and treatments

Three sets of the trials were conducted during SR 2011, LR 2012 and SR 2012 on a randomised complete block design with four replicates. A given replicate had six plots, each measuring 3.75 m (six maize rows) × 4.00 m (nine hills of two plants each). The treatments were made of three rates, 1.5, 2.5 and 3.0 L ha⁻¹ of Roundup Weather Max (RWMX) herbicide and one rate 2.5 L ha⁻¹ of Roundup Turbo (RTB) (Table 1). Un-weeded and conventionally tilled weed management systems were the fifth and sixth treatments, respectively. The six weed management treatments were randomised within

and between blocks, and any two plots within a block were separated by a 1.0 m buffer zone path to guard treatments from spilling over between plots. Likewise, any two replications were separated by a 2.0 m buffer zone for the same purpose.

Figure 1 Location of effect of glyphosate-based herbicide trial site in eastern Kenya

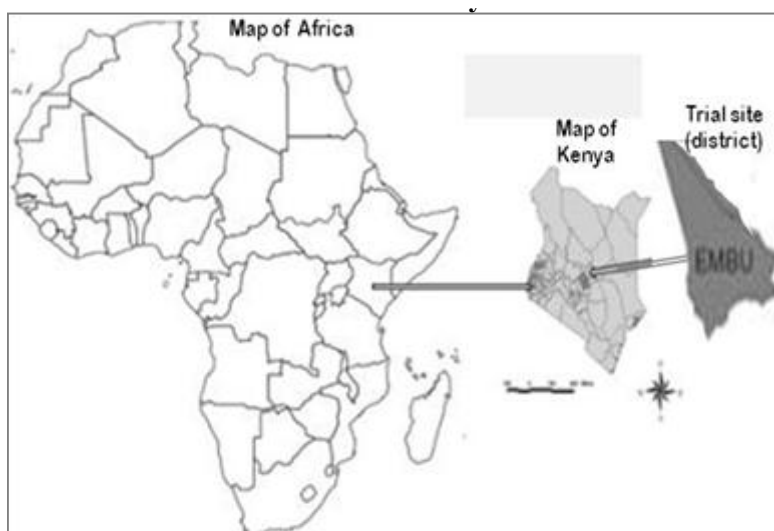


Table 1 Treatments description for glyphosate-based trials for the management of weeds in maize fields in humid areas, eastern Kenya

Treatment	Treatment Description		
	Rate of Herbicide (L ha ⁻¹)	Active Ingredient (gms Glyphosate L ⁻¹)	Weed management method
Roundup Weathermax	1.5	540	Herbicide sprays
Roundup Weathermax	2.5	540	Herbicide sprays
Roundup Weathermax	3.0	540	Herbicide sprays
Roundup Turbo	2.5	450	Herbicide sprays
Un-weeded control	Not applicable	Not applicable	No weeding
Conventional Weeding	Not applicable	Not applicable	Hand weeding

Glyphosate herbicide sprays were prepared and applied on the actively growing weeds every season, approximately one week after the on-set of the rains. The one-week planting delay was meant to allow weeds to start growing actively after going through periods of *dormancy* observed during dry spells witnessed prior to the start of the rains. Plots were marked out in weedy experimental fields, planted with medium maturity maize variety (var. DK 8031) spaced at 75 cm (between rows) and 50 cm (between hills). Three maize seeds were sowed in the weeds by carefully parting the weeds to access the ground and using sharp pointed hand tools, dibbo sticks (*muro*) and pangas (machetes), to minimise rigorous soil disturbance. A *muro* is locally handmade tool with a pointed wood or metal end and used by farmers for making seeding holes and weeding. Approximately 10 gm of N₂₃:P₂₃:K₀ fertiliser material was applied in each of the seeding holes in all plots.

Conventional tillage plots were prepared and planting holes made using conventional tools *folk-jembes* to achieve fine tilth for maize production. The glyphosate herbicide treatments were applied a day after seeding. Adequate amounts RTB and RWMX herbicide products were drowned from their containers using graduated syringe and transferring the contents into mixing buckets. The herbicide/water solutions were thorough mixed and then transferred into a pre-calibrated CP3 15-litre Knapsack hand sprayers fitted with a low volume herbicide application nozzle to deliver 200–250 L ha⁻¹ of the solutions which were evenly applied on the weeds in all but hand weeded and unweeded plots. Other field operations included thinning extra plants per station, insect pest control and hand weeding only in CVT-treated plots. The thinning to leave two plants per hill or to maintain 53,333 plants ha⁻¹ was done approximately four days after the crop emergence. The plants were dusted with borer-cide (*Bulldock*[®] 0.05 GR) at the rate of 6.5 kg ha⁻¹ to control stalk borers that are known to start invading maize plants immediately after the crop emergence causing up to 40% yield loss if not managed (Mula, 1995; Pingali, 2001). Two hand-weeding events per season were conducted only on the conventionally tilled plots at 15th and 85th day after the crop emergence.

2.3 Data management

Biophysical data sets were analysed using Analysis of Variance (ANOVA) method following statistical analysis procedures (Gomez and Gomez, 1984), and using Statistic Analysis System (SAS, 2002) computer programme. Net-benefits were computed to determine profitability of the various weed management systems for maize production in eastern Kenya region.

3 Results

3.1 Main weed species

Identification of weed species within the experiential area was done in the same day of treatment application. The aim of the exercise was to get baseline information on weed species and biotypes within species which may ultimately compete with the crop if not managed. Broad and narrow leaved weeds were found in the area where *Elymus repens* or couch grass (86%), *Richardia scabra* (82%) and *Oxalis* (67%) dominating the site in all three study seasons (Figure 2). *Bidens pilosa*, *Galinsoga parviflora*, *Cyperus spp.*, *Amaranthus spp.* and *Commelina spp.* were other common weed species. Majority of the weeds emerged within five to seven days after the start of the rains. This indicated that the weeds may have started competing with the crop for moisture, light and nutrients just at the time of crop emergence.

3.2 Percent (%) weeds suppression

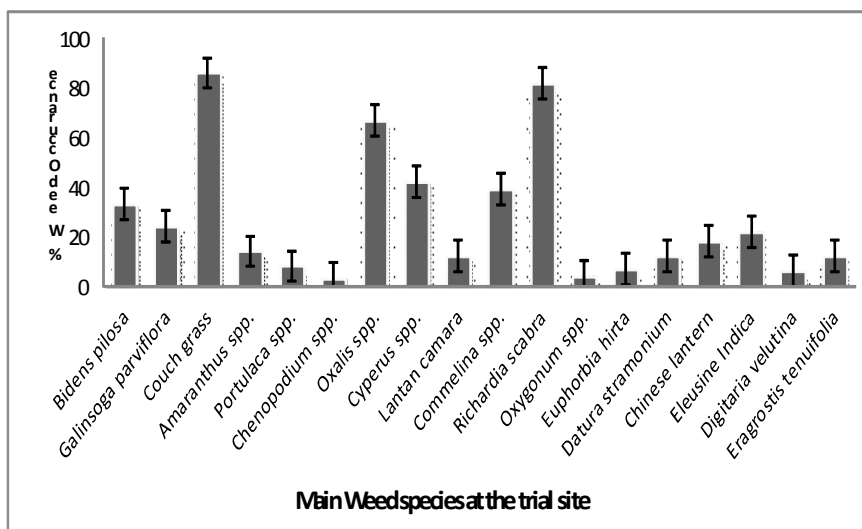
Percent weed ground cover parameter was used to provide guidelines on how weeds were suppressed by the various herbicide products and rates. This was achieved by using a 1.0 m² quadrant randomly thrown in a given plot, followed by visually recording weed suppression status therein. The activity was conducted three times in each of the three

seasons as weed suppression event: WS¹, WS² and WS³ observed 1, 2 and 3 months after treatments application. The information collected from the three events was later worked out into percent weed suppression (% ws) using the following formula:

$$\% \text{ ws} = \frac{(\text{Msut} - \text{Mst})}{\text{Msut}} \times 100$$

where Ws = weed suppression; Msut = mean score of un-weeded treatment; and Mst = mean score of a treatment.

Figure 2 Main weed species and their percent occurrence within the trial site during SR 2011, LR 2012 and SR 2012 seasons



The results show that the critical time that the weeds/crop competed vigorously for resources was just before the crop flowering (2½ months after the crop emergence). This was clearly witnessed in the un-weeded treatment whose %ws significantly ($p \leq 0.05$) differed from those of herbicides and conventional tilled treatments during the three seasons that the parameter was monitored (Table 2). The herbicide-treated plots had significantly better weed suppression compared to un-weeded and conventionally treated plots. The study observed that at least two hand weeding events should be conducted in a given season to keep off the weeds in conventional weeded fields.

3.3 Weed vigour

Information on weed vigour was recorded at the 1st, 70th and 120th day after the crop emergence or at treatments application, crop flowering stage and crop physiological maturity stage, respectively. This was achieved by visually observing the average weed vigour using scales of 1, 2, 3 and 4 representing 'very low', 'low', 'medium' and 'high' weed vigour, respectively. The hand hoed plots were free of weeds at seeding time due to preparation of fine and weed-free seedbeds. Low weed vigour was recorded in all herbicide-treated plots at the time of treatments application. However, the situation changed later on to medium weed vigour in conventionally tilled plots. This called for the

first hand weeding event that was done every season approximately 12 days after the crop emergence. There were significant declining trends in weed vigour from the start to the end of the seasons in all plots where the herbicides were applied. Decaying mulch was found on the soil surface at the end of the season in the herbicide-treated plots. This might have helped in conserving moisture for crop use during dry spells normally observed in later parts of the seasons. On a similar dimension, Baudron et al. (2013) reported that maize grain yields were increased due to conserved moisture caused by retention of mulch on soil surface. The rotting mulch greatly contributes positively to the soil physical property and organic matter pools particularly where conservation agriculture is practiced by farmers (Zibilske et al., 2002).

Table 2 Percent weed suppression during different periods of the season in a glyphosate-based trial for the management of weeds in maize fields, eastern Kenya

<i>Treatment</i>	<i>Herbicide Application Rate (L ha⁻¹)</i>	<i>Weeding/Tillage Method</i>	<i>Percent (%) WS¹</i>	<i>Percent (%) WS²</i>	<i>Percent (%) WS³</i>
RWMX	3.0	ZT	66.0 ^b	96.3 ^a	87.5 ^{ab}
Un-weeded control	N/A	No Till	0.0 ^d	0.0 ^d	0.0 ^d
CVT	N/A	CVT	88.5 ^a	35.0 ^a	91.8 ^a
RWMX	2.5	ZT	59.0 ^b	89.5 ^b	83.3 ^b
RTB	2.5	ZT	58.8 ^b	94.8 ^{ab}	89.0 ^{ab}
RWMX	1.5	ZT	49.5 ^c	82.8 ^c	75.3 ^c
Mean	–	–	53.6	66.4	71.1
LSD (0.05)	–	–	9.2	5.3	5.8
%CV	–	–	11.4	5.3	5.4

Notes: RWMX = Roundup Weathermax; RTB = Roundup Turbo; CVT = Conventional tillage; N/A = Not applicable; ZT = Zero tillage; WS¹ = Weed suppression event 1 observed one month after glyphosate herbicides application; WS² = Weed suppression event 2 observed 2½ months after glyphosate herbicides application; WS³ = Weed suppression event 3 observed 3½ months after glyphosate herbicides application. CV = Coefficient of Variation; LSD = Least Significant Difference. Means with the same superscript letter are not significantly different ($p \leq 0.05$).

3.4 Crop phytotoxicity

Plant phytotoxicity condition was considered to be any deviation from normal morphological or physiological changes due to biotic, abiotic or artificial influence. We therefore focused on scorching of the whole or parts of the plant; de-colouration of plant parts from the normal green colour for a healthy plant; deformation or dwarfing of all or some plants within a given plot. Extra ordinary maturity of plants was also taken as the phytotoxicity aspect. The assessments were made at the 30th, 70th and 120th day after the crop emergence using scores of 1, 2, 3 and 4, denoting 'low', 'medium', 'high' 'very high' levels of phytotoxicity, respectively. Only plants in un-weeded treatments are shown significant ($p \leq 0.05$) changes in de-colouration of plant leaves and dwarfing of plants (Table 3). The plants in the said plots died in approximately ten days earlier than those under conventional or herbicide-treated plots. This was attributed to crop/weeds competition for growth resources.

Table 3 Crop phytotoxicity score at different periods of the season in a glyphosate-based trials for the management of weeds in maize fields in humid areas of eastern Kenya

Treatment	Herbicide Application Rate (L ha ⁻¹)	Weeding/ Tillage Method	Phytotoxicity Score 1	Phytotoxicity Score 2	Phytotoxicity Score 3
RWMX	3.0	ZT	1.5 ^b	1.5 ^b	1.5 ^b
Un-weeded control	N/A	No Till	3.0 ^a	3.5 ^a	3.8 ^a
CVT	N/A	CVT	1.3 ^b	1.3 ^b	1.5 ^b
RWMX	2.5	ZT	1.5 ^b	1.5 ^b	1.0 ^b
RTB	2.5	ZT	1.5 ^b	1.5 ^b	1.3 ^b
RWMX	1.5	ZT	1.5 ^b	1.5 ^b	1.8 ^b
Mean	–	–	1.7	1.8	1.8
LSD (0.05)	–	–	0.6	0.8	0.8
%CV	–	–	24.5	31.0	28.1

Notes: RWMX = Roundup Weathermax; RTB = Roundup Turbo; CVT = Conventional tillage; N/A = Not applicable; ZT = Zero tillage; Phytotoxicity Score 1 = assessment done 30 days after the crop emergence; Phytotoxicity Score 2 = assessment done 70 days after the crop emergence; Phytotoxicity Score 3 = assessment done 123 days after the crop emergence. Means with the same superscript letter are not significantly different ($p \leq 0.05$); CV = Coefficient of variation; LSD = Least Significant Difference.

3.5 Maize days to 50% crop physiological maturity

Crop physiological maturity was arrived at when over 90% of the plants in a given plot stopped sinking nutrients due to age effect. An average of 126, 133 and 136 days for DK 8031 maize variety was recorded from emergence to physiological maturity in SR 2011, LR 2012 and SR 2012 trials, respectively. The un-weeded plots had the crop maturing significantly ($p \leq 0.05$) earlier than those under the hand and herbicide-treated plots. This was attributed to weeds withdrawing essential growth resources from the crop leading to stress due to nutrient deficiencies. Such plants reached physiological maturity (*died*) earlier than 135 days expected from the variety.

3.6 Maize shoot biomass and grain yields

Shoot biomass (above ground minus grains) and grain yields were determined at the crop physiological maturity stage or harvesting time. The two parameters significantly ($p \leq 0.05$) differed between un-weeded and the herbicide applied and conventionally tilled plots (Table 4). The three seasons average shoot biomass was 7.3 t ha⁻¹. The three rates 1.5, 2.5 and 3.0 L ha⁻¹ of RWMX provided significantly ($p \leq 0.05$) higher average biomass yields at 8.5, 9.5 and 9.2 t ha⁻¹, respectively, compared to un-weeded control that had 1.0 t ha⁻¹. Conventionally tilled treatments had 7.0 t ha⁻¹ average shoot biomass yields which significantly differed from that of un-weeded control. The observed grain yields had also similar trends like the ones of shoot biomass. The ZT treatments gave 4.4, 4.3 and 4.0 t ha⁻¹ grain yields from RTB (2.5 L ha⁻¹), RWMX (3.0 L ha⁻¹) and RWMX (2.5 L ha⁻¹) treatments, respectively. The yields from ZT treatments were not significantly different from one another in the three seasons that the study was conducted.

Table 4 Three seasons average maize shoot biomass and grain yields from glyphosate-based trials on weeds management in maize fields in humid areas of eastern Kenya

Weeding Method	Herbicide Application Rate (L ha ⁻¹)	Shoot Biomass (t ha ⁻¹)	Grain Yield (t ha ⁻¹)
RWMX	3.0	9.2 ^a	4.3 ^{ab}
Un-weeded control	N/A	1.0 ^c	0.1 ^c
CVT	N/A	7.0 ^b	3.6 ^b
RWMX	2.5	9.5 ^a	4.0 ^{ab}
RTB	2.5	8.6 ^{ab}	4.4 ^{ab}
RWMX	1.5	8.5 ^{ab}	4.5 ^a
Mean	–	7.3	3.5
LSD (0.05)	–	1.9	0.9
%CV	–	16.3	22.5

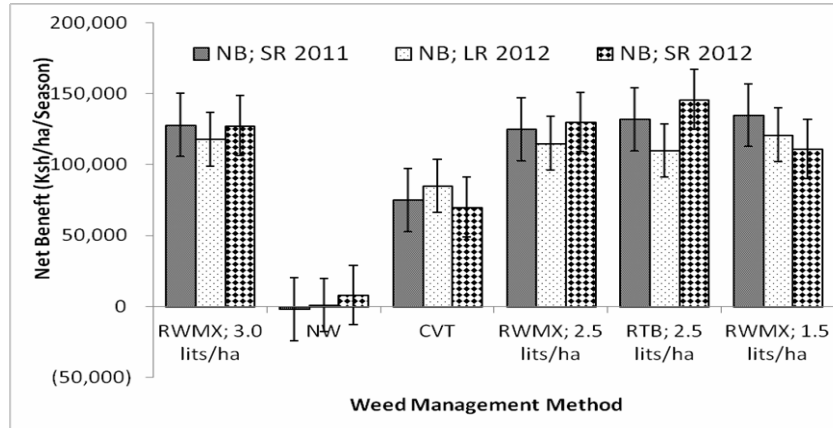
Notes: RWMX = Roundup Weathermax; RTB = Roundup Turbo; CVT = Conventional tillage; N/A = Not applicable; ZT = Zero tillage; Means with the same superscript letter are not significantly different ($p \leq 0.05$); CV = Coefficient of variation; LSD = Least Significant Difference.

Conventionally tilled plots had an average grain yield of 3.6 t ha⁻¹. This was not significantly different from those from ZT treatments. The lowest average grain yield was 0.1 t ha⁻¹ from un-weeded treatment, and significantly ($p \leq 0.05$) differed from those of conventional and herbicide treatments. Improved yields from CVT and ZT managed plots were attributed to better control under such treatments compared to un-weeded control plots where weeds/crop competed vigorously for growth resources.

3.7 Net benefits

Net-benefits (NB) of different weed management methods were done using information inputs/operations costs and output prices collected during the time of experimentation. The information came from the local agric-stockiest(s), scientists, farmers and other partners involved in maize industry in eastern Kenya. The exercise assumed that the average annual interest rate for money in a bank savings account as 12%; the herbicides were priced at Ksh. 1200 L⁻¹. The total cost for any herbicide was based on the rate(s) the product was applied at. Other assumptions were that the maize variety (DK 8031) took six months from sowing to marketing using farm-gate prices of Ksh. 2000 per ton of stovers collected from the farms by buyers using their own labour and transport; and that grains were sold at Ksh. 3000 per 90 kg bag. The number of empty bags needed to hold the grains was based on the total grain yield per treatment and that the grains were harvested, packed and sold out immediately with no storage cost to the farmer. The formula, NB = Total Cost (TC) – Total Benefits (TB) was used to work out the benefit a farmer could get from making use of the glyphosate-based herbicides in maize farming. The study realised average NB of Ksh. 99,797, 90,123 and 94,392 in SR 2011, LR 2012 and SR 2012, respectively (Figure 3). The NB from un-weeded treatment was every season significantly ($p \leq 0.05$) lower than what was observed from the ZT and CVT tilled plots.

Figure 3 Net-benefits (Ksh.ha⁻¹) per season of maize grown under different weed management methods during SR 2011, LR 2012 and SR 2012 seasons



4 Conclusions

The first, second and third season's results observed that the herbicides are effective means of weed management in maize grown under zero-tillage conservation agriculture systems. Roundup Turbo herbicide applied at 2.5 L ha⁻¹ and the three rates (1.5, 2.5 and 3.0 L ha⁻¹) of Roundup Weathermax herbicide performed comparatively well in weeds management. In addition, the herbicide products did not have any noticeable phytotoxicity on the crop, and also improved NB compared to results from un-weeded and the conventionally tilled fields.

The average maize grain yield was significantly ($p \leq 0.05$) lower in un-weeded compared to what were acquired under herbicides and CVT treatments. Crop yields from the herbicide treatments were not significantly different from one another in all three seasons. Conventionally tilled treatment had an average grain yield of 3.6 t ha⁻¹. This yield too was not significantly different from those from herbicide-treated plots. The lowest grain yield (0.1 t ha⁻¹) was from un-weeded treatment. This yield significantly ($p \leq 0.05$) differed from those of conventional and herbicide-treated plots.

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