EFFECTS OF PRECEDING CROP AND WEED CONTROL METHOD ON WEEDS AND COMMON BEAN (*Phaseoulus vulgaris* L.) YIELD IN A NO-TILLAGE CROPPING SYSTEM

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RESUMEN

En 1994, se inicio un trabajo de investigación el cual se continuo durante tres años, con el objetivo de evaluar el efecto de cultivos antecesores y métodos de control de malezas sobre el rendimiento frijol común (*Phaseolus vulgaris* L.) y la dinámica de las malezas. El frijol y los cultivos antecesores fueron sembrados en sistema de cero labranza. Las secuencias de cultivos estudiadas fueron: maíz (*Zea mays* L), seguido de frijol y frijol seguido de frijol. Se analizaron tres ciclos de los cultivos (1994, 1995 y 1996) . La secuencia de cultivo que produjo el máximo rendimiento fue maíz seguido de frijol en 1994, así como también el promedio de rendimiento a través de los años. Por otro lado, los mayores valores de vainas por planta y semillas por vaina se obtuvieron cuando el frijol antecedió al frijol en 1994. Parcelas con controles de malezas mecánico y químico obtuvieron menores densidades y peso seco de malezas y mejores rendimientos que aquellas parcelas en las cuales se controlo la maleza a través de cobertura muerta.

ABSTRACT

In 1994, a three-year study was initiated to evaluate the effects of preceding crops and weed control methods on common bean (*Phaseolus vulgaris* L.) yield and weed dynamics. Bean and the preceding crops were grown in a no-tillage system. The crop sequences studied were maize *(Zea mays* L.) followed by bean, and bean following bean. Three complete bean cycles (1994, 1995 and 1997) were analyzed. The crop sequence producing the largest average bean yield was maize followed by bean in 1994 and as an average over the years. In addition, more pods per plant and seeds per pod were produced when bean followed bean in 1994. Plots with mechanical and chemical weed control had a slightly lower weed density and weed dry weight, and larger bean yield than those with mulching.

Key words: Conservation tillage, mulching, Nicaragua, yield components, economic analysis, herbicides, crop rotation, crop circulation.

Abbreviations: d.a.p, days after planting; monocot, monocotyledons; dicot, dicotyledons; CS, crop sequence; WC, weed control; MU, mulching; ME, mechanical weed control; CHE, chemical weed control; NT, No tillage

Common bean is an important crop in Central America. In Nicaragua, beans have traditionally been grown in reduced tillage systems in the humid areas of the northern central region and in the humid areas of the Atlantic region (Abaunza, 1990). In the northern central region, residues are usually burned or removed from the field, while in the Atlantic region, bean is produced in traditional farming systems by planting without tillage (NT) into residues of fallow vegetation (Tapia & Camacho, 1988).

It has been estimated that 70 percent of the beans in this area are grown in a no-tillage system. In the Pacific region, beans are produced in both traditional, and conventional mechanized farming systems (Llano *et al*, 1998). Farmers usually plant the crop after maize (*Zea mays* L.), but in some areas planting the same species in sequence is not unusual. During the last ten years, common bean grown under no tillage has gained widespread acceptance in the Pacific region; on small and medium farms there is a great interest in this practice. Problems with soil erosion, loss of fertility, water retention and fuel and labor expenses are the most important arguments found in the literature for no tillage (Karlen *et al*, 1994).

Research within the Nicaraguan national bean program has focused on improving genetic materials, giving little or no attention to agronomic practices that could improve bean production. One such practice is weed control and the combination of weed control and other agronomic practices such as crop sequences.

Many researchers have pointed out that systems using a single species, compared to traditional systems that use different crop sequences, may suffer more damage from insect pests and pathogens (Altieri, 1997) and weeds (Liebman & Jenke (1990).

Other authors indicate that crop sequences using crops with different characteristics could improve nutrient cycling and control soil erosion more effectively; have lower production costs; and produce larger seed yields (Clegg and Francis, 1984). Some of these benefits are inherent to sequences, others depend on the crops planted and length of the sequence, and others still depend on the type of tillage, cultivation, fertilization and pest control practices used in the sequence (Karlen *et al.*, 1994).

Crop sequence can influence specific weed populations. Some species survive because they are adapted to the crop conditions; others appear as a secondary infestation while others fail to survive.

Planting two or more crops in sequence implies the use of different agronomic practices (cropping systems, fertilization, herbicides, etc.) which might restrict the appearance of some weed species and favor the establishment of others which are easily managed (Liebman & Janke (1990).

In small farm systems, commonly observed in the Pacific region of Nicaragua, crop sequence can be a significant factor determining weed behavior and performance of bean production.

Though bean following bean often produces smaller yields than bean following maize on the soil of this area, the difference can be greatly intensified depending on the way weeds are controlled. The effect is also such that common bean produces nearly equivalent yields under different weed control methods when it follows maize but much smaller yields in a bean-bean sequence (Solano, 1996).

Weed management in common beans is one of the agronomic factors with the largest impact on final yield, especially in areas with a low level of technology, on small or medium-sized farms. These practices are labour intensive and imply high production costs. Hence, it is important to develop alternatives that can reduce weeds effectively, without negatively affecting soil and environment. These alternatives must be low in cost and adequate for the existing production system.

The objectives of this study were to determine the effects of preceding crop and weed control practices on weed dynamics, yield components and yield of common bean (*Phaseolus vulgaris* L.).

MATERIALS AND METHODS

The field experiments were conducted on a sandy loam soil at the experimental farm La Compañia 1994, 1995 and 1997. Preceding crops were sown in May, and harvested in August (common bean) and in September (maize). The experiments were planted during the second part of the growing season (end of September) in each of the study years.

Rainfall. Patterns of rainfall during the period of 1992 to 1997 are presented in Table 1. Total rainfall during the period the crops were in the field (May-Oct) was 697, 1165 and 821 mm in 1994, 1995 and 1997, respectively. Rainfall during 1994 and 1997 was below the long-term average. However, planting in 1995 was delayed because of excessive rainfall during September. Rain was more

Table 1. Monthly precipitation (1992-1997) at the experimental station La Compañia

	May	Jun	Jul	Aug	Sep	Oct	Total
1992	87	159	119	62	143	114	685
1993	347	101	105	287	345	113	1298
1994	83	49	95	80	168	222	697
1995	21	212	112	326	291	203	1165
1996	241	222	282	117	275	316	1452
1997	14	292	58	82	99	276	821
Mean	132	173	129	159	220	207	1020

uniformly distributed in 1995 than in 1994 and 1997. Erratic precipitation in 1997 provided good conditions for growing common bean, due to low levels of fungi infection.

Experimental design. The design used was a split-plot with four replicates. The main plots contained the crop sequence, and the sub-plots the weed control treatments. The two crop sequences used were maize-bean, and bean-bean. The weed management treatments were mulching, mechanical weed control and chemical weed control.

The mulching consisted of applications of maize straw, at a rate of 4 500 kg ha^{-1}. The mulch was applied at planting; 160 dry maize plants were placed parallel to the rows in each sub-plot. Maize plants were obtained from the previous crop.

The mechanical control consisted of one hand-weeding operation, using machetes, 21 days after planting (d.a.p.). Previous research has indicated that the critical weed competition period in common bean is short; weed control ought to be carried out when the third trifolium start to develop. In varieties commonly used in Nicaragua, this period is around 21 days after planting (Alemán, 1989). During mechanical weed control, efforts were made not to disturb the crop.

The chemical control was done 21 d.a.p. A mixture of the herbicides fomesafen and fluazifop-butyl was applied at a rate of 0.75 l ha^{-1} of the commercial product of each herbicide. Fluazifop-butyl is a grass specific herbicide used in several dicot crops, which has proved to be effective in controlling monocots in common bean in Nicaragua (Alemán, 1997). Fomesafen is specific for broad-leaved weed species and commonly used in soya bean production, however, some references indicate that it could be use in common bean production without causing damage to the crop (Colquhoun *et al,* 1999).

Cultivation practices were maintained uniformly for the two crop sequences. The experimental field received no tillage during the two years preceding the establishment of the experiments (1992 and 1993). During that time, the crops planted were the same as those used in the crop sequence in the experiment. Planting was carried out under no tillage, the land was cleared of vegetation and planting was done in holes made with a pointed stick. At planting, NPK fertilizers were distributed in the row at a rate of 15 kg N, 39 kg P_20_5 and 13 kg K_2O ha^{-1}. This fertilizer level is estimated to adequately supply the nutrient needs of common beans in the Pacific region of Nicaragua (Talavera, 1989).

Data sampling. Weed seedling emergence for each type of plants (monocots and dicots) was recorded at 42 d.a.p, from a square meter randomly chosen in each sub-plot. After counting, seedlings were removed and the fresh weight was recorded. A sub-sample of 100 g of each type of plant was dried for 60 h to obtain a relation of dry weight to fresh weight. Weed species were identified every year. The height of ten, randomly selected bean plants from the central rows of the experimental units was measured at 21 and 35 d.a.p, in each experiment. Each year common bean was harvested from an 8-m^2 plot, and the total yield determined.

Analysis of variance and general linear models were used according to procedures provided by the SAS Institute (SAS, 1990). Data were analyzed first as a tri-factorial including years. The analysis indicated that a year ´ treatment interaction occurred, and therefore, data were analyzed for each year. The Fisher's unprotected Least Significant Difference test (P = 0.05) procedure was used to compare means. Analysis of variance was conducted on log (X + 0.5) transformed weed abundance and weed biomass data for each of the experiments to satisfy normality, additivity and homogeneity of variance requirements of ANOVA. The results presented are the original data means. Planned comparisons were made for certain treatments using single degree-of-freedom contrasts.

RESULTS

Weeds. The weed flora consisted of 34 species in the three-year study, 20 dicots and 14 monocots. Twenty-nine weed species appeared in the maize-bean crop sequence and 25 in the bean-bean sequence. The main differences were observed in the case of monocot species, where 12 species were found in the maize-bean crop sequence and eight in the bean-bean crop sequence. The main monocots weed species in the three-year study were *Cynodon dactylon* (L) Pers, *Cyperus rotundus* L., *Digitaria sanguinalis* (L.) Scop and *Ixophorus unicetus* (Presl) Schlecht. The main dicot weed species were *Amaranthus spinosus* L., *Argemone mexicana* L., *Euphorbia heterophilla* L., *Hybanthus attenuatus* (Humb E Bonpl), *Melampodium divaricatum* (L.) Rich et. Pers, and *Melanthera aspera* (Jacquin) L. C.

Weed density differed between years; a higher density was recorded in 1994 and 1997 than in 1995 for both types of plant. In most cases crop sequence did not affect weed density. The only significant differences were found in 1995 and 1997, when the density of monocots was larger in the bean-bean crop sequence than in the maize-bean crop sequence (Table 2).

Weed density was, in most cases, not affected by weed control methods. The only observed significant difference was found in 1994, when density of dicots, monocots and total weed density was higher with mulching and mechanical weed control than with chemical weed control (Table 2).

Significant interactions between crop sequence and weed control methods were observed in the case of dicots in 1994 and 1995.

The predominating weeds differed between the crop sequences. In the bean-bean crop sequence monocots were higher in number in 1995 and 1997, while in the maize-bean sequence dicots were more prevalent in the referred years. With mulching and mechanical weed control the proportion of dicots and monocots were similar, while with chemical weed control monocots were more prevalent.

Weed biomass did not differ between years, but interactions between years and crop sequences, and years and weed control were significant with no consistent effect, therefore the analyses for each year are discussed. For dicots in 1994, and monocots and total weed dry weight in

Table 2. ANOVA table of weed density (plants m^{-2}) influenced by crop sequences, and weed control methods. The statistical analysis was done on log (X+0.5) transformed data. Data shown are not transformed

		1994			1995			1997			Average over years		
		dic	mon	tot	dic	mon	tot	dic	mon	tot	dic	mon	tot
Crop sequence (CS)													
Bean-bean		316	318	634	53	199	252	192	338	530	187	285	472
Maize-bean		91	254	345	127	73	199	207	150	357	142	159	301
Weed control practices (WC)													
Mulching (MU)		228	221	449	88	79	167	226	215	441	181	172	352
Mechanical (ME)		303	398	700	106	137	243	259	285	544	223	273	496
Chemical (CHE)		80	240	320	75	192	267	114	232	345	90	221	311
CS	1	NS	NS	NS	NS	0.0369	NS	NS	0.0377	NS	NS	NS	NS
WC	2	0.0089	0.0389	0.0103	0.0004	NS	NS	NS	NS	NS	0.005	NS	NS
MU Vs. ME	1	NS	0.0276	0.083	NS	NS	NS	NS	NS	NS	NS	NS	NS
ME Vs. CHE	1	0.0055	0.0243	0.003	0.0003	NS	NS	NS	NS	NS	0.0021	NS	NS
CS*WC	2	0.001	NS	0.0192	0.0072	NS	NS	NS	NS	NS	0.0042	NS	NS

1995, higher weed biomass was recorded in the bean-bean than in the maize-bean crop sequence. Monocot species dominated the weed flora in the maize-bean crop sequence in 1994 and 1995 and in the bean-bean sequence in 1995 and 1997. Interaction between crop sequence and weed control was only significant for dicots in 1995.

Significant differences in weed biomass production were detected between weed control methods in all years, with the exception of monocots and dry weight total in 1995. Weed biomass was greater when weeds were controlled by mulching and mechanically than when they were controlled chemically in each study year (Table 3). Monocots were predominant in all the treatments, but more so in those with chemical and mechanical weed control.

Plant height. Bean plant height was not affected significantly by crop sequence. Plant height did, however, differ between weed control methods in 1994 and 1995, but not in 1997. Plants were significantly (P = 0.05) taller

Table 3. ANOVA table of weed dry weight (g m^{-2}) influenced by crop sequences, and weed control methods. The statistical analysis done on log (X+0.5) transformed data. Data shown are not transformed

		1994			1995			1997			Average over years		
		dic	mon	tot	dic	mon	tot	dic	mon	tot	dic	mon	tot
Crop sequence (CS)													
Bean-bean		84	79	162	48	112	159	22	60	82	51	83	135
Maize-bean		8	61	69	8	5	12	17	33	50	11	33	44
Weed control (WC)													
Mulching (MU)		90	91	180	31	93	123	34	68	102	51	84	135
Mechanical (ME)		40	84	124	48	35	84	20	61	82	36	60	96
Chemical (CHE)		7	35	42	5	46	51	5	11	15	6	31	36
CS	1	0.0139	NS	NS	NS	0.0051	0.007	NS	NS	NS	0.004	0.0086	0.0035
WC	2	0.011	0.0108	0.001	0.0002	NS	NS	0.0008	0.0019	0.0001	0.0001	0.0004	0.0001
MU Vs. ME	1	0.0496	NS	0.0344	NS	NS	NS	NS	NS	NS	NS	NS	0.0407
ME Vs. CHE	1	NS	0.0312	0.0197	0.0001	NS	NS	0.0042	0.001	0.0002	0.0003	0.003	0.0005
CS*WC	2	NS	NS	NS	0.0004	NS	NS	NS	NS	NS	0.0061	NS	NS
C.V.		33.6	16.9	14.1	34.6	30.0	16.8	31.4	36.1	20.2	19.4	11.7	9.1

when mulched than with mechanical and chemical weed control in both years (Table 4). It was observed that plants in mulched plots were not as vigorous as were those in plots with mechanical and chemical weed control.

Table 4. ANOVA table of plant height influenced by crop sequences, and weed control methods

		Plant height			
		1994	1995	1997	Average
Weed control (WC)					
Mulching (MU)		43.5	42.6	40.4	42.2
Mechanical (ME)		38.5	39.4	39.6	39.2
Chemical (CHE)		35.5	38.9	42.2	38.9
LSD		3.0	2.1	NS	2.3
Crop sequence (CS)	1	NS	NS	NS	NS
Weed control (WC)	2	0.0003	0.0057	NS	0.0174
ME Vs. CHE	1	0.0445	NS	NS	NS
ME Vs. MU	1	0.0033	0.0074	NS	0.0166
CS*WC	2	NS	NS	NS	NS

Yield components. Table 5 shows the effects of crop sequence and weed control methods on bean yield components. There was no difference between years regarding pods per plant, seeds per pod and bean plant per unit area. Seed weight was higher in 1995 than in 1994 and 1997. Pods per plant in 1994, and seeds per pod in 1994 and the average over the years were greater when bean followed maize (P < 0.05). Bean following bean produced heavier seeds than in the maize-bean sequence, while the preceding crop did not significantly affect plants per unit area.

Pods per plant, seeds per pod, and plant per unit area were not affected by weed control methods. Bean following maize produced more pods per plant in 1994 than in the other crop sequence. In 1995 and 1997 no significant differences were reported. None of these variables were influenced by treatment interactions. Seed weight was unaffected by the preceding crop, but was affected by weed control in 1995 and 1997. In both years, seeds in the treatment with chemical weed control were heavier than seeds in the mulched treatment, but not in the mechanical weed control treatment

Bean yield. Table 6 shows the effects of crop sequences and weed control methods on bean seed yields. Seed yield was higher in 1997 than in 1994 and 1995. Bean seed yield was affected by crop sequence in 1994. The maize-bean crop sequence gave a larger bean yield (P < 0.05) than the bean-bean crop sequence. The avera-

Table 5. ANOVA table of pods per plant, grains per pods, weight of grains and plants per unit area (yield components) affected by crop sequences, and weed control methods.

		Pods per plant				Seeds per pods			
Source	DF	1994	1995	1997	Average	1994	1995	1997	Average
Crop sequence (CS)	1	0.0056	NS	NS	NS	0.007	NS	NS	0.0457
Weed control (WC)	2	NS	NS	NS	NS	NS	NS	NS	NS
CS*WC	2	NS	NS	NS	NS	NS	NS	NS	NS

		Weight of seeds				Plants per unit area			
Source	DF	1994	1995	1997	Average	1994	1995	1997	Average
Crop sequence (CS)	1	NS	NS	NS	NS	NS	NS	0.026	NS
Weed control (WC)	2	NS	0.0004	0.0016	0.0003	NS	NS	NS	0.0329
ME Vs. CHE	1	NS	0.0037	0.0005	0.0002	NS	NS	NS	NS
ME Vs. MU	1	NS	NS	NS	NS	NS	NS	NS	NS
CS*WC	2	0.0096	0.0104	NS	NS	NS	NS	NS	NS

ge yield differences resulting from preceding crops were 28 percent between maize-bean and bean-bean, but this value was influenced by differences found in 1994 which were not directly related to the preceding crop.

Seed yield differed between weed control methods. In 1994 and 1995, bean yield in the treatment with chemical and mechanical weed control was larger than the yield in the mulched treatment. In 1997, bean seed yield was higher with chemical weed control, than with mechanical weed control and mulching. In addition, in 1997 the treatment with mechanical weed control yielded more than the mulched treatment. The average common bean yield in the different weed control treatments differed by 25 percent between chemical weed control and mulching, and by 6 percent between chemical and mechanical weed control. No significant interaction was observed between crop sequence and weed control methods.

plots. In plots with mulching weed plants have two strata, the first composed of plants that germinate after planting, and a second stratum composed of a later generation. This is probably why a higher weed density was observed in treatments with mechanical weed control. The larger weed growth in the first plant stratum in mulched plots led to low weed abundance.

The lack of interaction between crop sequence and weed control methods suggests that the weed control methods tested were equally effective in the two crop sequences used. The mechanical weed control treatment was comparable with chemical weed control in terms of weed suppression in 1994 and 1995, but this control gave a higher weed dry weight in 1997. Hand weeding in no-tillage plots was very tedious because care had to be taken not to disturb the soil. Most of the hand-pulled weeds regrew rapidly, which would explain why the use of herbicides controlled weeds more effectively in all the years. Results indicate that for common bean grown in non-tilled soils there are advantages in using herbicides for weed control in the Pacific region of Nicaragua.

Table 6. Effects of weed control strategy and crop sequence common bean seed yield (kg ha^{-1}) over a three-year period

		1994	1995	1997	Average over years
Crop Sequence (CS)					
Bean-bean		737	1151	1300	1063
Maize-bean		1566	1123	1395	1361
LSD		186	NS	NS	133
Weed control practices (WC)					
Mulching (MU)		996	881	1093	1009
Mechanical (ME)		1237	1276	1312	1275
Chemical (CHE)		1221	1253	1638	1352
LSD		135	222	132	85
CS	1	0.0008	NS	NS	0.056
WC	2	0.0035	0.0034	0.0001	0.0001
ME Vs. CHE.	1	NS	NS	0.0002	NS
ME Vs. MU.	1	0.0022	0.0022	0.0035	0.0001

DISCUSSION

Differences between years were large and significant for most variables registered. For both, weed density and weed biomass the maize-bean crop sequence showed smaller values than the bean-bean sequence. Differences were more evident when comparing results between years. In 1994 and 1997, rainfall was higher during October which could be the reason why weeds were more dominant than in 1995. Patterns of rainfall were similar during the two first years of the study, but completely different in 1997 (Table 1), when rain was moderate and more suitable for common bean production. Extremely high rainfall in the previous years probably promoted weed growth especially in the bean-bean sequence.

Weed data were recorded at 42 d.a.p. At this stage plants from plots with mechanical and chemical weed control were in their early development stages (weed control was done at 21 d.a.p.), in contrast to those in mulched

Altieri (1998) stated that weed populations are especially sensitive to changes in crop species and herbicides used from one season to the next. We know of few studies that involve common bean in crop sequence and the effects on weed density and biomass production. However, experiments involving other crops in sequence show advantages expressed as reduced weed density and dry weight comparable to maize-bean sequence in the present study. Dougovish *et al.*, (1999) working with winter wheat found weed density reduction in a 3-year rotation that provided superior control of annual grass weeds.

According to Liebman and Janke (1990) crop rotation will not eliminate interference from weeds, but it can limit built-up of weed populations and prevent major shifts in the composition of weed species. Research carried out in Nicaragua showed that maize used as a preceding crop for soybean and sorghum leads to a reduction in weed abundance in these crops (Zambrana, 1995). He argues that this is possible because of the effect maize exerts on weed establishment. When cucumber was used as a preceding crop, the weed population increased in the subsequent crop. Solano (1996) found that weed density was reduced in common bean fields when maize was used as a preceding crop. He recorded higher weed abundance when there was a bean-bean sequence preceded by no crop.

In contrast, Andersson & Milberg (1997) studied weed flora in relation to crop, crop rotation and nitrogen, and did not report any differences between crop rotations. (In another study, the same authors mentioned that crop rotation had little or no influence on the composition of weed flora (Andersson & Milberg, 1996)).

In the present study, yield response to crop sequence differed over years, with strong differences between sequences during the initial year. In 1995 and 1997 there was no evidence of differences between crop sequences. Differences in 1994 could not, however, be attributed to crop sequence. Field observation (data no recorded) showed fungal infestation in plots with the bean-bean rotation. The crop sequence started in 1992, so it could be argued that the inocule was present at that time. Despite this, differences in the health of the crops were not observed in the following years.

Other researchers have found yield advantages in crop sequences involving different species. Wolfe and Eckert (1999), in a two-year study, found greater maize grain yields when maize followed soybean compared with when maize followed maize. Similar results were shown by Janovicek *et al,* (1997) who argued that the preceding crop affects maize grain yield. Yields of maize following either soybean or spring wheat were 16 percent higher than those of maize following maize.

Weed control is a difficult task for farmers on small and medium-sized farms in Nicaragua, especially when no-tillage agriculture is used. Traditionally, mechanical weed control has been the main way of controlling weeds on these farms. This practice is used without any consideration being taken to weed-plant competition, consequently the practice is very labor intensive. The labor could be reduced if we consider that for common bean, it is enough to have one weed control carried out when the third trifolium starts to develop (approximately 21 d.a.p for varieties commonly grown in Nicaragua). Controlling weeds mechanically gave a similar result as the use of two herbicides in two of the years. One of the problems with mechanical weed control is its incompatibility with the objectives of no-tillage agriculture, but in the case of common bean, one complete mechanical operation during the critical competition period (Alemán, 1989) gave good results.

The use of herbicides could be another option for weed control in common bean in the Pacific region, but in that case, other considerations should be taken into account, such as economic and environmental costs.

Mulching as a mean of weed control in common bean reduced weed growth during the early stages, but at the end of the cycle weeds reached the level of the crop and suppressed it. Despite little weed abundance during the critical competition period, late competition and problems at harvesting constitute limits to the use of mulching. However, despite few good results from mulching in the present study, the use of crop residues should be studied as a base of integrated management. The combination of mulching and another measure for weed control, for example selective mechanical weed control, should be studied in the future. In the proposed system, after the maize is harvested, the stalks are left in the field to reduce erosion and the decline soil fertility. More studies are required of mulching used as a weed control strategy. Questions such as the amount of residues required for weed suppression, how the mulch should be placed and the combination of mulching and another method of weed control should be tackled in future research.

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