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Winter Broccoli Performance and Nutrient Quality When Grown by Conservation Tillage

D. J. Makus

U. S. Dept. Agriculture, Agricultural Research Service, Subtropical Agricultural Research Center, Weslaco, TX 78596

ABSTRACT

Winter broccoli (*Brassica oleracea*, L. Botrytis Group) production was evaluated under three tillage systems, conventional (CT), minimum tillage (MT), and no-till (NT), which were established in August, 1994. Cotton, followed by a legume, preceded broccoli in the yearly rotation. After three growing seasons, marketable broccoli yields were similar among tillage systems. However, plant densities at harvest were lower in the NT system compared to the CT-grown broccoli plants. No-till-grown broccoli heads compensated for stand differences by producing slightly larger heads (*P*=0.17). The percent marketable yield was not affected by tillage practice. Floret NO_3, chlorophyll, and carotenoid concentrations were reduced when broccoli was grown under MT and NT systems. At the end of the third growing season, the amount of germinable weed seeds in the upper 0-5 cm of soil was highest in the NT soil. Total plant weed populations were higher in conservation tilled soil. Total N, K, and Mg concentrations in the upper 30 cm soil profile were highest in the NT system. Total N, C, K, Mg, and P nutrient gradients were greatest in NT soil, whereas Na concentrations were greatest in CT soils. Min. tillage responses were generally intermediate to those of CT and NT.

RESUMEN

Se evaluó la producción de brócoli (*Brassica oleracea*, L. Botrytis Group) en temporada de invierno bajo tres sistemas de labranza, convencional (LC), mínima (LM) y no labranza (NL), los cuales se establecieron en agosto de 1994. Se cultivó algodón, seguido por una legumbre, antes del brócoli en la rotación anual. Después de tres estaciones de crecimiento, los rendimientos de la venta del brócoli fueron similares en los diferentes sistemas de labranza. Sin embargo, las densidades de plantas al momento de la cosecha fueron menores en el sistema de NL en comparación con las plantas de brócoli que crecieron en el de LC. Las plantas de brócoli que crecieron en el sistema de no labranza produjeron cabezas ligeramente más grandes (*P*=0.17) lo que compensó por las diferencias entre las parcelas. El porcentaje de rendimiento de venta no fue afectado por la práctica de labranza. La concentración de NO_3, clorofila y carotenoides se redujo en los flósculos cuando el brócoli se cultivó bajo sistemas de LM y de NL. La cantidad de semillas de maleza germinables en la capa de los 0-5 cm superiores del suelo fue mayor en el sistema NL al final de la tercera estación de crecimiento. Las poblaciones totales de malezas fueron mayores en el suelo sometido a labranza de conservación. Las concentraciones totales de N, K, y Mg en los 30 cm del perfil superior del suelo fueron mayores en el sistema de NL. Los gradientes de nutrientes totales de N, C, K, Mg, y P fueron mayores en el suelo bajo sistema de NL, mientras que las concentraciones de Na fueron mayores en los suelos con LC. Las respuestas observadas en el sistema de labranza mínima fueron generalmente intermedias a aquellas en los sistemas de LC y NL.

Additional index words. *Sustainable, no-till, Brassica oleracea Botrytis Group*

Long-term conservation tillage practices have been reported to improve soil tilth, aggregate particle size, organic matter, reduce water and wind-blown soil erosion, improve early-season moisture, water infiltration, soil microbial populations, avian habitat, alter fungi and insect pressure, and reduce power and labor required for tillage operations (Beare et al., 1997; Blevins and Frye, 1993; Dick, 1997; Jordan et al., 1997; Karlen et al., 1994; Subbarao and Hubbard, 1996; Tyler et al., 1994).

Disadvantages to conservation tillage include surface compaction, reduced early season soil temperatures, poor seed bed preparation and vertical plant pest displacement, deep water percolation, and increased use of agrichemicals (Buhler et al., 1997; Dick, 1997; Sumner et al., 1986; Tyler et al., 1994; Uri, 1997).

Conservation tillage systems have given mixed benefits with respect to ground water quality, furrow irrigation efficiency, and vegetable disease control (Christensen et al., 1994; Sturz et al., 1997; Sumner et al., 1986; Tyler et al., 1994).

Conservation tillage practices are in widespread use in agronomic crop production. Adapting traditional NT practices to horticultural row crops, particularly warm-season vegetables, have generally been uninspiring (Grenoble and Bergman, 1980; Knavel et al. 1977; Mullins et al.; 1988). However, the use of winter cover crops, in conjunction with strip tillage and/or herbicidal destruction of the cover crop, has been more effective, particularly in temperate climates, in assuring both economic and ecological sustainability (Hoyt et al.,1994). Strip tillage of fall broccoli in a permaculture site has shown

Table 1. Effect of three tillage sytems on broccoli field performance pooled over harvest years 1995, 1996 and 1997[z]

	Plant stand	Mkt yield[y] at 1st harvest	Marketable[x] Yield	Head wt.	No.	Total	Cull Yield	Heads
	(/haX10^4)	(%)	(t/ha)	(g)	(/haX10^4)	(% of)	(t/ha)	(/haX10^4)
Year:								
1995	5.08 ab	92 a	6.11 a	157 a	3.92	95 a	0.32 b	0.69 b
1996	5.47 a	--	4.43 b	118 c	3.74	87 b	0.62 a	1.33 a
1997	4.69 b	27 b	4.91 b	133 b	3.70	94 a	0.30 b	0.52 b
	*	**	**	**	NS	**	**	**
Tilage:								
Conventional	5.42 a	58	5.17	132 b	3.87	90	0.52 a	1.03 a
Min. tillage	5.17 ab	60	5.16	135 b	3.83	93	0.39 ab	0.78 b
No-tillage	4.65 b	60	5.08	142 a	3.62	94	0.34 b	0.73 b
	*	NS	NS	0.17[v]	NS	NS	0.11	0.14

[z]There were no year by tillage interactions.

[y]Excludes 1996, when there was only one harvest for marketable heads.

[x]Heads trimmed to 15 cm length, with minimum butt dia. of 2.5 cm.

[w]NS, *, ** = not significant, and significant at $P<0.05$ and $P<0.01$, respectively.

[v]Probability of a greater 'F' value.

some promise (Makus, 1993a).

The objective of this study was to determine the effect of tillage practice on broccoli floret and yield and soil nutrient levels during the initial three years of a continuous three crop per year rotation in a subtropical semiarid environment.

MATERIAL AND METHODS

Three tillage systems, consisting of conventional, minimum tillage, and no tillage, were established in Aug., 1994, in a Hidalgo silt loam (fine-loamy, mixed, hyperthermic Typic Calciustolls) near Weslaco, Tex. (Lat. 26° 13'). Prior to Aug., 1994, crops planted at the experimental site were conventionally managed. CT consisted of plowing, dicing, bedding, cultivation, spraying, and shredding operations. No-till consisted of leaving the soil undisturbed after the previous crop, utilizing a stalk puller to loosen stubble before planting, applying an additional herbicide for weed control, and shredding plant stand after harvest. Minimum tillage differed from NT in that both bedding and cultivation practices were utilized. Plowing and dicing operations were not used, as in CT; and wing plows were used when necessary to loosen soil from rooted stubble.

Legume green manure crops, consisting of *Vignia unguiculata*, cv. 'Texas Pinkeye' (in 1994 and 1995), and *Crotalaria juncea*, cv. 'Sunn Hemp' (in 1996), were seeded and grown 4 to 8 weeks prior to seeding broccoli. Seeds of 'Galaxy' (1994 and 1996) and 'Baccus' (1995) were sown at a rate of 0.56 kg /ha. Rows were on 0.75 m centers in 9.1 m wide x 91 m long plots. In the spring of each year, cotton was planted into the same tillage systems.

Broccoli was direct seeded with a Gaspardo planter (Solex Corp., Dixon, Calif.) on 17 Nov. 1994, 22 Nov. 1995, and 28 Oct. 1996. Nitrogen (as ammonium nitrate) was split-applied at a rate of 60 kg/ha at the 4 and 9 leaf stages by spoke wheel injection and furrow irrigation, respectively. Prefar (bensulide) was applied pre-plant at a rate of 5.6 kg a.i./ha. Insecticides were used at similar rates and frequency in all tillage treatments. Plants were furrow irrigated before soil moisture tension reached 30 k Pa.

At each initial harvest, floret sub-samples (1 cm dia. x 5 cm length) were removed from the apical portion of 10 heads per plot. These were frozen, lyophilized, ground through a 40 mesh (0.36mm^2) screen and stored at -20° C until analyzed. On 26 Feb. 1997, 20 random samples from the row centers within each plot were removed with a 2 cm dia. soil sampler at depths of 0-5, 5-10, and 25-30 cm. Part of the sample was used to determine soil seed bank counts, gravimetric soil moisture; the remaining sample was dried at 70° C for 48 hrs and then stored at room temperature until analyzed for soil pH, organic matter, electrolytes, total N, C, and soil mineral nutrients. Mineral elements were determined by ICP, percent total N and C by combustion, NO_3 by specific ion electrode (Plank, 1992), and pigments by the spectrometric method of Welburn and Lichtenthaler (1984).

The experimental design was a randomized complete block design with four replications. Location of the tillage treatment remained the same each year; and years were analyzed as repeated measures. Differences between means were tested using the PDIFF option of the LSMEANS statement of PROC GLM of SAS Version 6.04.

RESULTS AND DISCUSSION

Mean temperature and rainfall for the three broccoli growing seasons, Nov. through Feb inclusive, were 18.9 C and 64 cm, 16.9 C and 65.8 cm, and 17.0 C and 20.2 cm for 1994-95, 1995-96, and 1996-97, respectively. Broccoli heads were harvested 7 Feb. 1995, 13 Feb. 1996, and 30 Jan. 1997. Second harvests were required approx. one week later in 1995 and 1997, but not in 1996.

Marketable broccoli yields and the percentage of marketable heads were similar between tillage systems (Table 1). Cull weights and the number of culled heads tended to be higher in broccoli grown under CT. This may have been due to plant density differences between tillage treatments. Plant stand was

Table 2. Nutrients from broccoli florets grown under three tillage systems in 1995, 1996 and 1997.

	P	Ca	Mg	NO_3	Fe	Zn	Al	Cu
	(%)			(μg g⁻¹)				
Year (Y):								
1995	0.58 b	0.44 b	0.20 c	3434 b	130 a	20 b	6 c	6.4 c
1996	0.62 b	0.66 a	0.27 a	5185 a	88 b	27 a	16 b	6.0 b
1997	0.70 a	0.43 b	0.23 b	2942 b	59 b	28 a	26 a	8.3 a
	**[z]	**	**	**	**	**	**	**
Tilage (T):								
Conventional	0.65	0.51	0.24	4203 a	104	24	18	6.9
Min. Till	0.62	0.50	0.23	3773 ab	95	24	16	6.8
No-till	0.63	0.51	0.24	3584 b	77	27	15	7.2
	NS	NS	NS	*	NS	NS	NS	NS
Interaction:								
T x Y	NS	NS	NS	NS	NS	NS	NS	NS

[z]NS, *, **=not significant, significant at P<0.05, P<0.01, respectively. Mean separation at probability level shown.

Table 3. Effect of conservation tillage on pigments from broccoli florets harvested in 1995, 1996 and 1997.[z]

	Chlorophyll					
	'a'	'b'	Total	a:b ratio	Total carot.	Carot: chloro ratio
Year (Y):						
1995	0.48 b	0.17	0.65 b	2.8 b	0.19 b	3.5 a
1996	0.51 ab	0.17	0.68 ab	3.0 a	0.20 ab	3.3 b
1997	0.56 a	0.18	0.74 a	3.0 a	0.22 a	3.4 b
	0.07[x]	NS[y]	0.11	**	*	**
Tilage (T):						
Conventional	0.55 a	0.18 a	0.73 a	3.0	0.22 a	3.4
Min. till	0.49 b	0.17 b	0.66 b	2.9	0.20 b	3.4
No-till	0.50 b	0.17 b	0.67 b	2.9	0.20 b	3.4
	*	0.06[x]	*	NS	*	NS
Interaction:						
Y x T	NS	NS	NS	NS	NS	NS

[z]No significant year x tillage interaction.
[y]NS,*,**=not significant, significant at P<0.05, P<0.01, respectively. Mean separation at probability level shown.
[x]Probability of a greater 'F' value.

reduced in the no-till system compared to CT, but head weights were highest in plants grown under NT. Plant compensation associated with plant density would likely account for the yield similarities, however, the relationship between plant stand and head weight was weak (r=0.23, *P*=0.18). Year differences were observed for all agronomic attributes recorded except marketable number of heads/ha. There were no year x tillage interactions associated with field performance.

Nitrate levels in broccoli florets were lower in NT-grown broccoli compared to CT-grown broccoli (Table 2). Lowering NO_3 concentrations in food crops is generally desirable (Maynard and Barker; 1972). Other nutrients were not effected by tillage system. Of the 13 nutrient concentrations determined, K, S, Ca, Mg, NO_3, and Na were highest in 1996. This may have been do to the more advanced head maturity and the need for only one harvest in 1996 and/or cultivar differences. Floret Fe and Mn were found in highest amounts in 1995, whereas P, Al, and Cu concentrations were found in highest concentrations in 1997. Tillage x year interactions occurred for N, K, S, Na, and Mn (Fig. 1).

Florets from CT-grown broccoli were higher in chlorophylls and carotenoids compared to conservation tillage-grown broccoli (Table 3). This was not visually observable in the field. Floret chlorophyll and total carotenoid concentrations were higher in 1997 than in 1995. Lower light intensity during the cool and cloudy 1996-97 growing season may account for these pigment differences (Makus, 1993b). The ratio of total chlorophylls to carotenoids was highest in 1995. Pigment responses were consistent between years.

Soil electrolyte (Table 4) and Na concentrations (155 vs. 478 kg/ha) increased between 1994 and 1997. This was probably associated with a decline in irrigation water quality, acerbated by a three-year drought, which has been documented for this watershed during the last 21 years (Miyamoto et al., 1995). Increasing sodicity can have a negative impact on soil structural stability and permeability. Soil total N concentrations (1222 vs. 1598 kg/ha) increased an average of 30%. This appeared to be a consequence of both cover crop use and tillage practice. The NO_3 concentrations between 1994 and 1997 were associated with sampling after the post plow-down of a legume, versus sampling after the harvest of a heavy feeding Brassica crop. There appeared to be some enhancement in P (77 vs. 104

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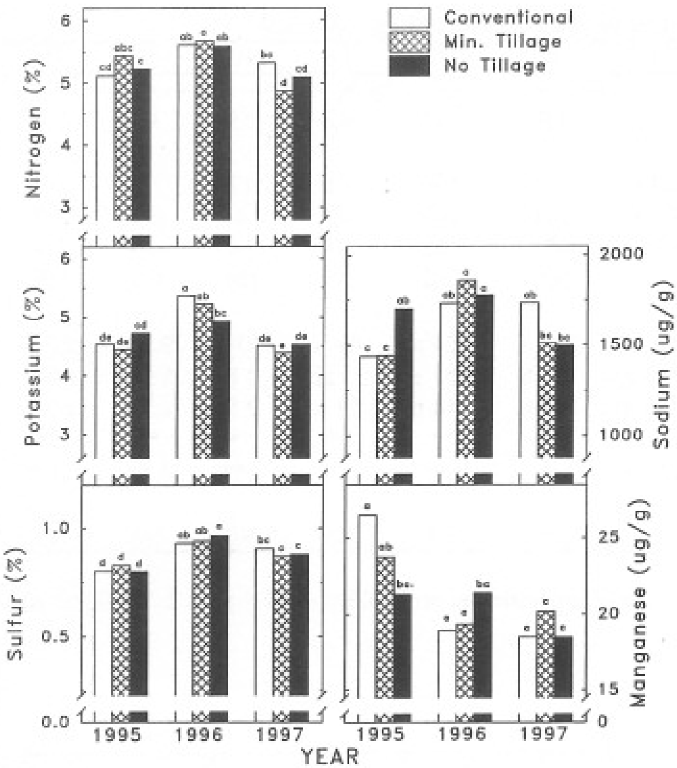

Fig. 1. Interactions between tillage treatment and year for broccoli floret N, K, S, Na, and Mg. Lower case letters are used to separate mean differences (*P*=0.05)

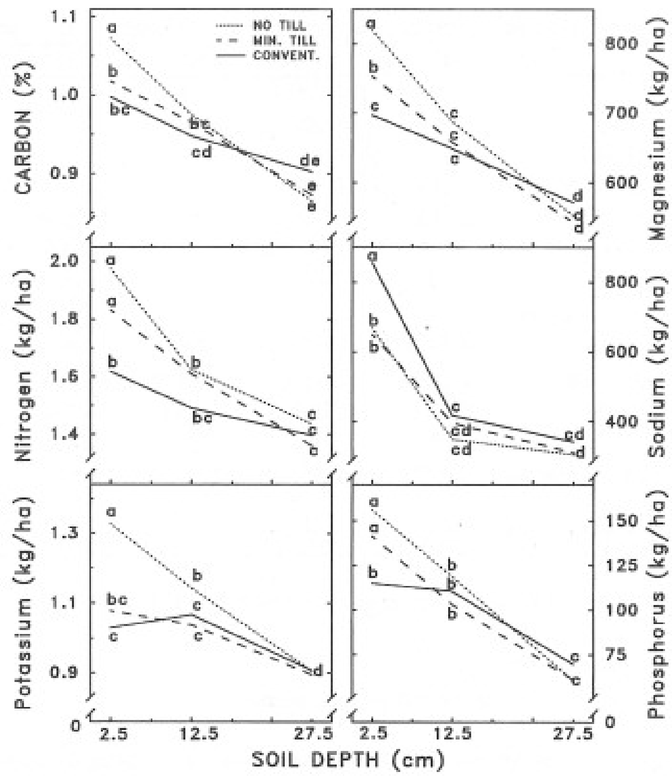

Fig. 2. Interactions between tillage treatment and siol depth for soil C, N, K, Mg, Na, and P. Lower case letters are used to separate mean differences (*P*=0.05)

kg/ha), S, Fe, and B, and a decrease in Mn over time. Ammonium nitrate was the only fertilizer applied during this period. Although no pH changes were observed, continuous NT over a 10 year period can reduce soil pH, particularly when legumes were used in the rotation (Burle et al., 1997).

At the end of the third year of repetitive tillage practices, the NT system resulted in increased soil N, P, K (*P*=0.09), and Mg, and decreased soil Na concentrations in the upper 30 cm profile compared to conventional tillage (Fig. 2). Minimum tillage was intermediate in these nutrient changes. Increased concentrations of soil C, N and several mineral nutrients in the 0-5 cm profile of NT soils may be associated with slower mineralization by soil microflora in what are characteristically cooler NT soils (Alvarez et al., 1995). Long term conservation tillage after years 9-14 resulted in yearly C increases of 0.06 %, in a Norfolk loamy sand. During this period, the C concentration at the 0-5 cm depth was almost twice that of CT soil (Hunt et al., 1996).

As soil depth increased, organic matter (%), N, P, K, Mg, Mn, NO_3, B, and Zn concentrations decreased linearly (L); electrolytes, Na, and S decreased quadratically (Q) with soil depth; and pH increased (Q) under CT and MT and linearly in NT management (Table 4, Fig. 2). Iron levels slightly increased (L) with soil depth.

Nutrient gradients in the upper 30 cm profile were greater in NT soil compared to CT soil for N, K, and Mg; whereas Na gradients were greater in CT than in the two conservation tillage systems (Fig. 2). Phosphorus levels did not decrease between the two upper sampling depths in the CT soil compared to the conservation-tilled soils. Soil Cu (3.0 kg/ha) was not affected by tillage system or soil depth. Franzluebbers and Hons (1996) reported that, after 8.5 years of monocropped wheat, sorghum, or combination rotations, NT soils had lower pH, Fe, and Cu than CT soils, and greater P, K, Zn, and Mn at the 0-5 cm depth.

The ratio of C to N was reduced ($P<0.10$) between CT and NT. This would be expected, since the higher soil microbial biomass generally associated with NT soils slows N mineralization. The C:N ratio increased (L) with soil depth, because soil organic matter decreased more rapidly with soil depth than did total soil N (Table 4, Fig. 2).

Predominant winter weeds growing at the end of the 1997 harvest were London rocket (*Sisymbrium irio*, L.) > annual sowthisle (*Sonchus oleraceus*, L.) >> common purslane (*Portulaca oleracea*, L.) (data not shown). London rocket and 'total' weed populations were 3.4 ($P<0.005$) and 2.4 ($P<0.001$) times higher, respectively, under conservation tillage compared to CT (data not shown). There were no statistical differences in weed populations between the two conservation tillage systems.

The germinable soil seed bank levels were highest in NT, followed by MT, and then CT in the upper sampling range, but not different at the 25-30 cm soil depth (Fig. 3). Deeper seed placement in the soil can result in an exponential reduction in the number of weed seed; however, shallow placement and tillage has the opposite effect (Mohler and Galford, 1997). Sahoo et al. (1995) reported that CT increased the total buried weed seed population by 3 to 4 times compared with NT, but reduced the proportion of viable dormant seeds in the 0-20 cm

Table 4. Soil pH, conductivity, organic matter, and nutrients after three years of different tillage practices.

	pH	EC	OM	C:N ratio	Ca	S	Mn	Fe	NO_3	B	Zn
		(dS M^{-1})	(%)		----------------------------------(kg ha^{-1})----------------------------------						
Initial[z]:	7.97	0.28	--	--	10217	129	171	42	55	3.5	2.1
Tillage(T):											
Conventional	8.13	0.59	0.67	14.2 a	10218	195	150	51	12	7.1	1.9
Min. Tillage	8.14	0.50	0.72	13.5 ab	10214	171	148	49	8	6.1	1.7
No-tillage	8.12	0.54	0.72	13.0 b	10391	179	152	51	14	6.6	1.9
	NS[Y]	NS	NS	0.10[X]	NS	NS	NS	NS	NS	NS	NS
Soil depth (D):											
0-5 cm	8.03 b	0.87 a	0.76 a	12.8 c	9999 b	278 a	154 a	49 b	30 a	9.7 a	2.2 a
10-15 cm	8.19 a	0.40 b	0.70 ab	13.8 b	10369 a	144 b	151 ab	51 ab	4 b	5.5 b	1.8 b
25-30 cm	8.18 a	0.36 b	0.66 b	14.2 a	10455 a	132 b	144 b	52 a	2 b	4.7 b	1.5 b
	**	**	**	**	**	**	**	**	**	**	**
Polynomial fit:	Q**[w]	Q**	L**	L**	L**	Q**	L**	L**	L**	L**	L**
Interaction:											
T X D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]Based on 0-30 cm profile.

[y]NS,*,**=not significant, significant at $P<0.05$, $P<0.01$, respectively. Mean separation at probability level shown. L, Q=linear and quadratic, respectively.

[x]Probability > 'F' value.

[w]Linear fit, only, in no-till management.

profile. Feldman et al. (1997) reported that tillage systems such as NT cause less soil disturbance and result in a more diverse seed bank. In this experiment, no differences in winter weed species were apparent (data not shown).

There were no differences between tillage treatments in gravimetric soil moisture at the time of soil sampling (data not shown). No differences in insect damage to broccoli due to tillage treatment were observed. Bottenberg et al. (1997) reported that the presence of purslane or pigweed at 6 plants/m^2 reduced insect pest damage to cabbage even when insecticides were applied. Schellhorn and Sork (1997) observed that predator insect populations were substantially increased when *Brassica oleraceae* plots had weeds of non-Brassicaceae species present compared to no weeds or plots containing weeds of Brassicaceae spp.

Plant growth dynamics, plant architecture, potential pest competition, availability of supplemental water, and environment, such as growing season, are important factors to consider in selecting vegetable crops for the successful implementation of conservation tillage practices. In this study, MT and NT broccoli, grown during the cooler months in our semiarid, subtropical area, performed as well as CT broccoli with respect to marketable yield, visual appearance and mineral nutrient floret composition.

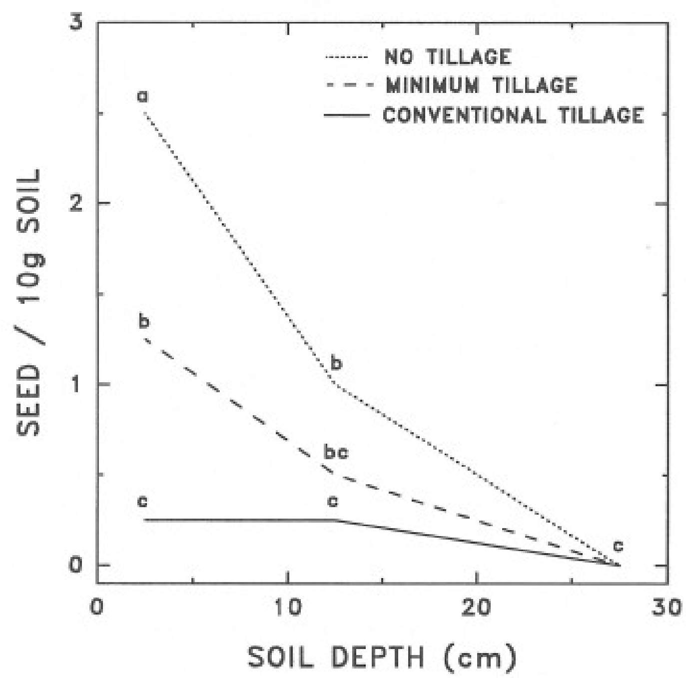

Fig. 3. Interaction between tillage treatment and soil depth for soil seed bank levels. Lower case letters are used to separate mean differences (P=0.05)

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