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Research Article

The effects of different tillage methods on the post-wheat second crop sesame: seed yield, energy budget, and economic return

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Abstract: Field experiments were carried out to assess the effects of different tillage practices on second crop sesame (*Sesamum indicum* L.) after wheat (*Triticum aestivum* L.) during the growing seasons of 2008 and 2009 in Aksu, Antalya, Turkey. The experimental design included no-till sowing into wet soil (NTW), no-till sowing into dry soil (NTD), reduced tillage (RT), and conventional tillage (CT) with 3 registered sesame cultivars, Muganli-57, Gölmarmara, and Özberk. In the no-till methods, the field was passed over only once for planting, which was directly performed into soil with stubble. In the RT method, the soil was not inverted and the field was tilled only once with a powered rotary tiller. The CT method consisted of 1-time moldboard plowing and 2-time disc harrowing, and leveling. According to the seed yield means of 2 years, the RT method provided the highest yield with a value of 855.2 kg ha^{-1}, while the lowest yield was recorded for NTW with a value of 413.0 kg ha^{-1}. Statistically, the RT and CT methods produced higher yields than the no-till methods. In addition to seed yield, days to 50% flowering, stem length to the first capsule, plant height, number of capsules per plant, and number of seeds per capsule were positively affected by the RT and CT methods. As expected, the no-till methods resulted in significantly less fuel consumption, with 7.5 L ha^{-1}, than RT (26.4 L ha^{-1}) and CT (71.5 L ha^{-1}). Although the no-till methods provided higher energy savings and lower land preparation costs, they fell behind RT and CT in regard to seed yield. When fuel consumption, inputs, and seed yield were considered together, the RT method was the most economical. Therefore, the RT method was advised to farmers for second crop sesame after wheat with the highest income potential.

Key words: Conservation tillage, no-till sowing, reduced tillage, seed yield, sesame, *Sesamum indicum* L.

Introduction

Sesame (*Sesamum indicum* L.), one of the oldest oilseed crops, has been cultivated in tropical and subtropical areas since ancient times. It is an important crop because of its oily paste, known as tahini, high oil content (Arslan et al. 2007; Uzun et al. 2008), and great antioxidant value (Erbas et al. 2009). In addition, sesame possesses some agricultural advantages such as the ability to grow well under tropical and subtropical climates with soil moisture without rainfall or irrigation, and grow as mixed stands with diverse crops (Ashri 2007).

Sesame production has declined recently in many sesame producing countries, including Turkey. Sesame production of the world and Turkey was 3.5 million and 26,000 tons in 2006, and 3.3 million and 20,000 tons in 2007, respectively (FAO 2008). Contrary to the decline in production, the need for sesame is steadily growing for human consumption and health. Seed shattering (Uzun et al. 2004), indeterminate growth habit (Uzun

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and Cagirgan 2009), undeveloped cultivars, poor cultural practices and management, some diseases, low harvest index, and poor crop rotations (Ashri 2007; Furat and Uzun 2010) all contribute to lower production. Lack of mechanized harvest also increases the cost of production. Above all, the high cost of sowing sesame deters some farmers, causing them to cease sesame production. Production practices should therefore be reconsidered for sustainable and profitable sesame farming.

A number of management strategies have been used in agricultural systems. If these strategies are used with new technologies, production costs can then be reduced significantly. Hence, sustainable farming systems need an immediate positive economic impact and alternative agricultural methods that will increase agricultural production while reducing inputs and threats to the environment (Govaerts et al. 2005). Conservation tillage is considered one of these alternative agricultural methods. Reduced tillage or no-till methods may provide sustainable sesame production since more than 40% of the total energy was spent only for seedbed preparation (Canakci et al. 2005). These methods also provided approximately 30% less tractor work for the post-wheat second crop sesame (Özmerzi and Barut 1996).

Tillage methods affect input costs, seedling emergence, bulk density, evaporation, weed competition, and the root system (Lampurlanes et al. 2001; Govaerts et al. 2005). Different tillage methods are used in various agricultural production systems around the world. Recently, reduced and no-till methods have gained popularity. The employment of no-till or reduced tillage has been shown to be economical (Sağlam et al. 2000; Polat et al. 2006), favorable, useful for soil aggregation, and helpful in reducing soil erosion (Huang et al. 2008). Furthermore, reduced tillage methods combined with crop residue retention on the soil surface can increase moisture infiltration and water use efficiency (Govaerts et al. 2005). Additionally, the reduced and no-till methods reduce the time spent in crop operations (Lampurlanes et al. 2001). This is crucial for wheat-sesame rotation, especially in the Mediterranean climate. As time is limited for second crop sesame after wheat, getting rid of wheat residues and disrupting and mixing soil must be done in the shortest period of time, or avoided altogether if possible. Traditionally, producers till their soils after burning the stubble. On the other hand, after wheat harvest, insufficient soil moisture requires irrigation before tillage. Following irrigation, a minimum of 5-7 days must pass for a good moisturizing of the soil. Irrigation, moisturizing, seedbed preparation, and the sowing phase of the second crop require a period of at least 10 days in total after harvesting wheat. As with sesame, if there is any delay in the sowing time in other second crops, it reflects negatively on the yield. Due to these constraints, short sowing processes are very important for modern, sustainable, and intensive sesame farming. For these reasons, alternative farming methods of no-till and reduced tillage were compared with conventional tillage methods in sesame production. To this end, no-till methods into stubble and reduced tillage were comparatively investigated to identify the impacts of these methods on yield and yield components of post-wheat second crop sesame.

Material and methods

Experimental fields

This research was carried out in Aksu, Antalya (36°52′N, 30°50′E; altitude, 15 m) during the 2008 and 2009 growing seasons. The genetic material of the study comprised 3 sesame cultivars, Muganlı-57 (M), Gölmarmara (G), and Özberk (O), which were provided by the West Mediterranean Agricultural Research Institute of Turkey. The field was used for 2 consecutive years to provide similar soil conditions. The treatments included 4 tillage methods: conventional tillage (CT), reduced tillage (RT), no-till sowing into wet soil (NTW), and no-till sowing into dry soil (NTD).

Field conditions

The soil was analyzed and found to be 15% sand, 55% silt, and 30% clay, which can be characterized as clay loam. Moisture contents of the soil for the top 50 mm, measured before the sowing processes, were 16.7%, 16.3%, 18.6%, and 3.5% for the CT, RT, NTW, and NTD plots, respectively. This indicated that the NTD plots fell behind the others in humidity since they were not irrigated prior to sowing. Fertilizers were applied to the plots at the rate of 60 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1}, and 60 kg K_2O ha^{-1} for all of the treatments. During the experiment, weed culling was manually done for all of the plots. In the CT and RT methods, weed culling was done once, while in the no-till methods it was done 3 times. This different implementation was assessed for labor cost for the economical computations. No fungicide, herbicide, or growth regulators were applied to any of the plots in any of the treatments.

Climatic conditions

Climatic data including monthly temperature, precipitation, and moisture values were collected by the State Meteorology Station in the 2 experimental years (Table 1). The 2 experimental years showed similar trends in air temperatures, with the highest in June, July, and August and the lowest in May. The growing season of 2008 received slightly less rainfall than did 2009, which was higher than the long-term averages for May, September, and October. Humidity was generally similar in the 2008 and 2009 growing seasons and the results were in compliance with the long-term averages.

Tillage practices

Wheat was the primary crop grown in rotation with sesame in the experimental field. The wheat was harvested with a combine harvester leaving relatively uniform stubble on 6 and 10 June in 2008 and 2009, respectively. Wheat residue biomass was determined immediately after harvesting. Sampling was performed randomly per plot. Residue samples were dried and then weighed to define the dry mass of the residue per hectare (kg ha^{-1}).

A modified vacuum seeder was used for no-till sowing into dry and wet soils. The seeder was designed for row crops by the Sonmezler Company (Adana, Turkey) and can sow directly into stubble. For hill dropping, a seed plate with 36 holes was added to the modified vacuum seeder. The seed metering system was adjusted for a nominal hill spacing of 11 cm in the row and 3 seeds were sown to every hill of each soil tillage implement. The seeds of the 3 sesame cultivars were sown directly into dry stubble soil without tillage (NTD plots) using the modified vacuum seeder on 10 and 12 June in 2008 and 2009, respectively. Except for NTD, the other treatments were irrigated by furrow irrigation. When soil moisturizing was provided, the RT, NTW, and CT plots were sown on June 20 in both 2008 and 2009. In the NTW method, the same direct sowing processes were replicated. In the RT method, a powered rotary tiller was used once for seedbed preparation. A rotary tiller, which is a combined tillage machine, has chisel tines, a rotary cultivator, and roller mechanisms. In the CT method, moldboard plowing to an approximate depth of 300 mm, disc harrowing (twice), and leveling (twice) were used to consolidate the soil, to crush clods, and to smooth the surface. A standard pneumatic seeder was used for the CT

Table 1. Monthly and long term averages of the climatic data in the experimental area*.

Months	Temperature °C			Humidity (%)			Rainfall (mm)		
	2008	2009	Long-term averages (30 years)	2008	2009	Long-term averages (30 years)	2008	2009	Long-term averages (30 years)
May	21.1	21.1	20.3	62.7	63.6	66.0	5.2	83.9	31.8
June	27.1	26.8	25.3	57.3	56.4	59.0	0.6	0.3	7.9
July	29.5	29.4	28.3	56.4	57.0	56.0	0.0	0.6	2.0
August	30.2	29.2	27.8	60.8	55.3	59.0	20.4	0.0	2.1
September	26.0	25.4	24.3	64.2	58.9	60.0	6.6	60.6	8.6
October	22.1	23.0	19.5	52.0	60.3	61.0	13.0	31.3	76.2

*Turkish State Meteorological Service.

and RT methods. These soil tillage implements are commonly used in the Antalya region of Turkey.

Economical computations

Input and output values of agricultural operations of sesame cultivated in the region were determined according to Canakci et al. (2005). Tillage operations, seedbed preparation, sowing, weeding, irrigation, fertilizer application, harvesting, and the tractor's energy expenditure were calculated for all of the treatments as suggested by Yaldiz et al. (1993). The total budget was made as recommended by Erenstein (2009).

Fuel consumption was measured using the following method: before starting the field test, the engine's fuel tank was completely filled. The quantity of fuel required to fill the tank after the tillage operation in the test field was measured using a 1 L graduated cylinder. Thus, the fuel consumed during the test was determined (Kalsirisilp and Singh 2001).

Experimental design and data analysis

The experimental design consisted of randomized split blocks with 3 replications. The main plots were NTD, NTW, RT, and CT. The sub-plots consisted of the 3 different varieties of sesame seeds. The average area of the plots was approximately 0.5 ha and their lengths ranged from 100 to 150 m. Inter- and intra-row spaces were arranged for 70 and 11 cm, respectively. At maturity, the plots were harvested by hand on 1 and 2 October in 2008 and 2009, respectively.

Data for some of the international standard sesame descriptor characters (IPGRI and NBPGR 2004) such as seed yield (kg ha^{-1}), plant height (cm), number of branches, stem length to the first capsule (cm), number of capsules per plant, number of seeds per capsule, time to first flowering (days), time to 50% flowering (days), and 1000 seed weight (g) were obtained for each plot. Percent emergence of seeds was determined from 25 m of row on the 17th day after sowing. The data acquired were analyzed using the general linear model procedures of the Statistical Analysis System. Means were compared by the least significant difference (LSD) test, at P = 0.05 and P = 0.01. LSDs were calculated for different main effectors to identify the relations between components.

Results

Tillage effects on income

Budget indicators of the selected crop showed that the RT method provided a better financial advantage in comparison to the other methods (Table 2). The net income was US$1264.30 in the RT method (Table 2). This was followed by the CT method, with the value of $997.10. The no-till methods fell behind the other methods with regard to net revenue, with $513.30 and $257.60 for NTD and NTW, respectively. Tillage effect on income was also assessed for tractor work, and thus fuel consumption. RT had lower energy input, with 26.4 L ha^{-1} fuel consumption, than CT (71.5 L ha^{-1}) (Figure).

Table 2. Crop budgets for NTD, NTW, RT, and CT methods based on the data of 2 years.

	Tillage methods			
	NTD	NTW	RT	CT
A. Gross revenue (seeds, US$ ha^{-1})	1199.3	963.6	1995.5	1788.4
B. Total cost (US$ ha^{-1})[a]	686.0	706.0	731.2	791.3
Of which land preparation and crop establishment (US$ ha^{-1})	40.0	70.0	95.2	155.3
C. Net revenue (A-B, US$ ha^{-1})	513.3	257.6	1264.3	997.1

[a] Total cost includes land preparation and crop establishment, fertilizer, labor cost, irrigation, harvesting, diesel consumption, and interest.

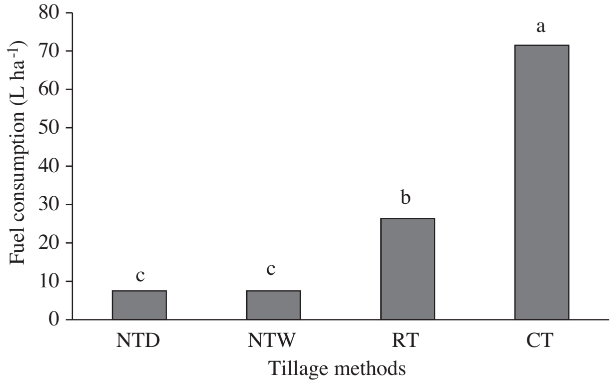

Figure. Average values of fuel consumption of tillage methods. Means followed by the same letter are not statistically different according to Duncan's multiple range test (P = 0.05).

Although the no-till methods required less tractor passes, and therefore lower energy input (7.5 L ha^{-1}) than the other implements, they resulted in insufficient income due to low seed yield (Table 2). The NTD and NTW methods thus fell behind CT and RT in regard to both gross and net revenue. Compared to the CT and RT methods, NTD and NTW yielded a negative profit of a little above $500 per hectare (Table 2).

Tillage effects on seed yield and its components

The amount of remaining residues after wheat harvest was determined for each plot. The highest amount of residue was recorded in the no-till plots for both years (Table 3). Compared to the no-till methods, residue covering was very low in the CT and RT plots. The crop residue left on the soil in the no-till systems caused planting to be more laborious and resulted in a lower germination percentage (Table 4). The results of the statistical analysis showed significantly different emergence rates of seeds due to the tillage systems in 2008 and 2009, while the cultivars and cultivar × tillage interactions created no significant differences. The emergence rate of NTD and NTW was lower than the RT and CT methods. The CT and RT methods had a significantly higher plant number per hill for all of the varieties of sesame because of the higher percentage emergence of these tillage systems (Table 4).

Seed yield was significantly affected by tillage treatments, cultivars, and cultivars × tillage interaction in the growing seasons of 2008 and 2009. In these 2 years, the highest yields of seed were obtained by the RT and CT methods (Table 5). Lower

Table 3. Summary of surface residue properties on tillage treatments.

	Residue cover ± standard deviation (kg ha^{-1})			
	No-till sowing into dry soil	No-till sowing into wet soil	Reduced tillage	Conventional tillage
2008	2230 ± 157	2235 ± 159	202 ± 15	92 ± 7
2009	2078 ± 151	2066 ± 149	170 ± 14	90 ± 7

Table 4. Effect of different tillage methods on seedling emergence rate (%).

Tillage methods	Muganlı-57		Golmarmara		Ozberk	
	2008	2009	2008	2009	2008	2009
No-till sowing into dry soil	30.3c*	29.8c	32.2c	28.9c	31.4c	26.3c
No-till sowing into wet soil	35.7b	32.9b	36.7b	33.4b	39.2b	32.6b
Reduced tillage	50.4a	50.1a	51.3a	52.5a	50.7a	51.1a
Conventional tillage	52.9a	50.6a	53.2a	54.7a	54.9a	53.1a

* Means followed by the same letter are not statistically different according to Duncan's multiple range test (P = 0.05).

seed yield was observed in the no-tillage methods, especially in NTW, which substantially fell behind the other tillage systems. There was no significant difference between the direct sowing methods of NTD and NTW for seed yield. A similar result was valid for the RT and CT methods. However, the RT and CT methods produced higher yields than NTD and NTW. The CT and RT methods roughly resulted in at least 38% higher seed yield than the no-till methods when taking into account the mean of the 2 years. Corresponding with results from the current study, RT along with CT consistently produced the highest sesame yield in both years despite the use of different cultivars. This potentially represents a significant improvement in sesame yield through better agronomic practices compared to the traditional CT method (Table 5).

A statistical analysis of yield components confirmed that some traits were highly dependent on tillage applications. However, they were less affected by interactions and cultivars (Table 5). Statistically, the number of capsules per plant was similar among the cultivars, but different among the tillage methods. The RT and CT methods were more effective on capsule production than the no-tillage methods. This was also true for plant height. Tillage methods had a significant impact on plant height but cultivars did not make any difference. RT and CT resulted in more branches than the no-tillage methods in 2009. The number of seeds per capsule was also affected by the tillage implements. The number of seeds per capsule was the highest in the RT and CT methods for both years. Different from other characters, 1000 seed weight showed normal distribution among the tillage methods and the measurements were very close to each other.

Discussion

No-till methods consistently had an important cost saving effect (Table 2), while the RT method provided a 45.1 L ha^{-1} fuel-saving compared to the CT method (Figure). The CT method required the highest energy input, making it disadvantageous. Similarly, Rathke et al. (2007) found that the CT method required the highest energy inputs and the no-tillage method required the lowest energy inputs in corn and soybean, respectively. Öztürk et al. (2006) reported that the machinery and fuel inputs for the tillage operations were reduced by 53.7% with minimum tillage compared to CT in corn production. In correlation, we had a 63.07% energy difference between the RT and CT methods.

NTD and NTW seemed to be better methods in reducing the cost of land preparation. This was the result of less tractor work, fuel consumption, and labor costs. The NTD method also had an additional advantage since it required no irrigation before the sowing process. However, these total cost savings were not sufficient to equalize financial expenditures because of the drastic reduction observed in seed yield and yield components when shifting from RT or CT to no-tillage methods. Bennett et al. (1998) noted that no-till methods had a low seed yield compared to the other tillage methods. They found that sesame seed yield in conventional tillage plots increased approximately 2-fold in comparison to no-till plots. Correlatively, no residue treatment increased the yield in sesame (Söğüt et al. 2009). The seed yield, not only of sesame but also of wheat, was slightly but significantly lower in the no-till method compared to CT and minimum tillage (Rieger et al. 2008). As a result, the no-till methods did not make a significant contribution to the seed yield in sesame.

Some unfavorable conditions led to lower seed yield in the no-till methods. Weed density and residue covering were important problems for no-till farming. In this study, it was observed that sesame plants in the no-till plots were under pressure of high density of weeds compared to CT and RT. Higher labor costs were therefore needed for combating weeds in the no-till methods. According to Chhokar et al. (2007), weeds were significantly denser in no-till methods than in CT in a rice-wheat rotation. Therefore, weeds must be destroyed properly using cultural practices and/or herbicide applications in no-till methods. When effective and timely control of weeds is accomplished, economical and sustainable yield might be achieved in no-till methods. Another important reason for lower seed yield seems to be plant residues in no-till methods. High levels of residue affects were observed in the no-till methods (Table 3), and thus reflected negatively on seedling emergence (Table 4). Furthermore, residues might affect water evaporation, soil erosion (Epplin et al. 1993), soil structure, and performance of the seeder used for no-till sowing (Canakci et al. 2009).

Table 5. The effects of tillage methods, cultivars, and their interactions on seed yield and its components.

Tillage methods (TM)	Cultivars (C)	Days to first flowering		Days to 50% flowering		Stem length to the first capsule (cm)		Number of capsules per plant		Number of branches		Plant height (cm)		Number of seeds per capsules		1000 seed weight (g)		Seed yield (kg ha^{-1})	
		2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
NTD	M	37.3	38.3	41.0	43.3	64.0	41.7	56.7	42.3	2.0	4.0	143.7	98.3	73.3	70.7	3.7	3.7	386.7	615.5
	G	37.3	37.7	40.3	40.3	56.7	45.0	74.7	44.7	2.3	5.3	137.0	119.0	69.3	70.7	3.7	3.5	646.7	480.1
	O	38.3	38.0	42.0	42.3	46.0	46.0	42.7	47.7	2.0	4.3	123.7	109.0	73.3	66.7	3.8	3.3	371.4	587.6
NTW	M	38.7	38.0	41.3	42.7	52.7	45.0	72.0	59.0	2.7	5.3	134.0	115.7	77.3	72.0	4.0	3.8	384.8	363.1
	G	39.0	39.3	42.0	42.0	41.0	37.7	55.3	52.3	3.0	5.0	119.0	105.3	72.0	69.3	3.9	3.9	554.3	301.2
	O	40.0	49.0	43.0	43.0	49.0	48.3	67.0	49.7	2.7	5.0	124.3	117.7	76.0	72.0	3.8	3.3	495.2	379.4
RT	M	37.0	38.7	42.0	43.0	63.3	52.3	80.0	69.3	3.0	5.7	144.0	136.7	81.3	74.7	3.5	3.6	652.4	1180.8
	G	39.0	38.7	42.0	42.0	49.0	49.7	69.3	70.3	2.7	6.0	134.7	129.0	72.0	74.7	3.6	2.9	920.0	843.1
	O	40.7	40.7	43.7	43.0	59.3	49.0	89.7	73.7	3.0	6.0	147.0	127.3	78.7	73.3	3.5	3.0	762.9	772.2
CT	M	38.7	39.3	42.0	43.0	58.3	48.7	81.0	90.7	2.8	7.0	146.0	128.0	80.0	73.3	3.7	4.0	635.2	1007.5
	G	39.3	38.7	42.3	43.7	55.7	44.7	77.3	81.3	3.0	7.3	146.3	133.0	70.7	76.0	3.8	3.5	910.5	613.1
	O	40.0	39.7	42.7	43.3	58.0	41.7	89.0	77.0	3.4	7.3	141.7	125.7	74.7	76.0	3.7	3.5	724.8	707.8
LSD_{TM}		0.31**	ns	0.54**	0.88*	6.87*	4.83*	9.61**	6.22**	ns	0.90**	8.94**	8.21**	1.49**	3.26**	ns	0.11**	182.14**	215.04**
LSD_{C}		0.27**	ns	0.46**	0.76*	5.95*	ns	ns	ns	ns	ns	ns	ns	1.29**	ns	ns	0.10**	157.74*	186.23*
$LSD_{TM \times C}$		0.74**	1.74*	0.93**	1.54*	ns	ns	ns	27.3*	ns	1.61**	17.65*	18.43**	3.18**	ns	ns	0.21**	323.89*	495.9*

*. **: Statistically significant at P = 0.05 and P = 0.01 significance level, respectively. ns: not significant.

Therefore, plant emergence caused a reduced rate of normal growth (Table 4). This result was supported by Natera et al. (2002), who reported that the no-till system caused a lower emergence percentage in sesame. Additionally, Oplinger and Philbrook (1992) noted that plant emergence in soybean was lower in no-till methods.

The number of capsules per plant and plant height are the 2 most important characters that affect seed yield in sesame (Yol et al. 2010). The obtained values for the characters were higher in the CT and RT methods than those of no-till, resulting in higher seed yield in the CT and RT methods. Similarly, Sarder and Rosario (1995) specified that tillage resulted in a higher plant height (14%-20%) than no-till methods in sesame planted after wetland rice. Other yield components also did better in the CT and RT methods, further proving that both tillage systems had similar impact on yield components.

In this study, sesame seed yield, yield components, fuel consumption, land preparation costs, and tillage effects were emphasized. The interactions of these parameters indicate that the RT method can easily replace CT. Farmers do not need to make any extra investments for purchasing special equipment for RT when they use this method with a powered rotary tiller. As the cost of fuel increases, RT is expected to gain popularity. The RT method can potentially change traditional tillage practices in sesame production. If no-till sowing processes with low fuel consumption are preferred, weeds must be combated properly. However, this task may require extra input and increase production costs. Furthermore, no-till treatments produce less seed yield than the other tillage systems. Thus, in view of continuously decreasing worldwide production of sesame, no-till methods are not currently appropriate for use, whereas the RT method offers better practical application prospects for second crop sesame production. Therefore, the RT method was advised to farmers for second crop sesame after wheat because of its income potential.

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