Iran Agricultural Research 14:175-201 (1995)

FUEL REQUIREMENTS AND MACHINE CAPACITY FOR TILLAGE AND PLANTING OPERATIONS ON A CLAY LOAM SOIL IN ISFAHAN

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(Received: August 2, 1995)

ABSTRACT

There is little information on fuel consumption and machine capacity of tillage and planting operations in Iran. The performance parameters of a range of tillage and planting implements for conventional tillage, tine-implement (non-inversion) tillage, and till-planting systems in wheat experiments in Isfahan, Iran were determined. Fuel consumption, effective machine capacity, field efficieney, and forward speed for various primary and secondary tillage and planting operations were measured. The effective working depth and width, wheel slip, and volume of soil disturbed were also determined for primary tillage operations. The tillage operations were a) moldboard plowing, b)chisel plowing, c)plowing with a locally made implement named Khishchee, d) disking after plowing, e) rotary tilling after chiseling and, f) disking after disking. The planting operations were a) planting with a grain drill in the tilled

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soil, and b)till-planting with a cultivator combine drill in the untilled soil. Throughout the experiment a 53kW two-wheel-drive tractor was used except for the till-planting operation where a two-wheel-drive 51 kW tractor was used. The experiments were conducted on a clay loam soil. Results showed that plowing with Khishchee had the highest fuel requirement and the lowest machine capacity. Although fuel consumption was the same for both chisel and moldboard plowinf, the machine capacity of the chisel plowing was 44% higher than that of moldboard plowing. In comparing the performance of the rotary tiller and the disk harrow, the machine capacity of the rotary tiller was half but its fuel requirement was 63% more. In comparing the performance of the grain drill working in the tilled soil and the cultivator combine drill working in the untilled soil, the fuel consumption of the grain drill was about half, but its machine capacity was twofolds..

تحقیقات کشاورزی ایران

۱۴: ۱۷۵-۲۰۱(۱۳۷۴)

نیازهای سوختی و ظرفیت ماشین های عملیات خاک ورزی وکاشت درخاک لومی رسی در اصفهان

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به ترتیب استادیار گروه ماشین های کشاورزی،دانشکده کشاورزی،دانشگاه صنعتی اصفهان و کارشناس بخش تحقیقات مهندسی زراعی،مرکز تحقیقات کشاورزی اصفهان،ایران.

چکیده

اطلاعات اندکی درمورد مصرف سوخت وظرفیت ماشین های عملیات خاک ورزی وکاشت درایران موجود است. پارامترهای عملکردی تعدادی ا ز ادوات خاک ورزی وکاشت استفاده شده درسیستم های خاک ورزی مرسوم، بی برگردان ورزی و ورز-کاشت برای گندم آبی دراصفهان " اندا زه گیر ی شدند. سوخت مصرفی ،ظرفیت مؤثر، ماشین ، بازده مزرعه ای وسرعت پیشروی برای عملیات خاک ورزی اولیه و ثانویه وکاشت اندا زه گیری شدند .همچنین عمق وعرض کارمؤثر، لغزش چرخ های تراکتور وحجم خاک بهم خورده برای عملیات خاک ورزی اولیه تعیین شدند. عملیات خاک ورزی شامل : الف) شخم با گاو اهن برگرداندا ر ب) شخم با گاو آهن قلمی ج) شخم با ماشین محلی بنام خیش چی ،د) دیسک زدن بعد ا ز شخم ،ه) خاک همزنی باماشین خاک ورز دوا ر (روتیواتور) بعد ا ز شخم با گاو اهن قلمی و)دیسک زدن مجدد زمین دیسک خورده بودند. عملیات کاشت شامل: الف) کاشت با خطی کار غلات در بستر تهیه شده ،ب) ورز-کاشت با یک خطی کار همراه باکولتیواتور در زمین شخم نخورده بودند. درتمام آزمایش ها یک تراکتور دوچرخ محرک ۵۳ کیلو واتی بکارگرفته شد درحالیکه برای عملیات ورز-کاشت ا ز یک تراکتور دوچرخ محرک ۵۱ کیلوواتی استفاده گردید. آزمایش ها دریک خاک با بافت لومی -رسی انجام شدند. نتایج نشان داد که شخم با خیش چی بیشترین مصرف سوخت وکمترین ظرفیت ماشینی راداشت . اگر چه مصرف سوخت برای شخم باگاوآهن برگرداندار و قلمی یکسان بود، ولی ظرفیت ماشینی گاوآهن قلمی ۴۴ درصد بیشتر ا زگاوآهن برگرداندا ر بود. درمقایسه عملکرد ماشین خاکورز دوا ر بادیسک ،ظرفیت ماشین خاک ورز دوار نصف ،ولی سوخت موردنیاز آن ۶۳ در صد بیشتربود . مقایسه عملکرد خطی کار که دریک بستر

تهیه شده کار می کرد، با خطی کار همراه با کولتیواتور که درزمین شخم نخورده کارمی کرد، نشان داد که مصرف سوخت خطی کارنزدیک به نصف ظرفیت ماشینی آن دو برابر خطی کار همراه باکولتیواتور بود.

INTRODUCTION

Mechanical tillage is the most commonly used method for altering physical soil conditions, and there are numerous implements and implement types avaliable for performing both primary and secondary tillage operations. Conventional tillage system in Iran is generally based on the use of the moldboard plow for primary tillage and disk harrow for secondary tillage. Many other implements can be employed for primary and secondary tillage including chisel plows and rotary tillers.

One of the problems in evaluating the different tillage systems for a crop production is lack of information on the performance parameters of the different implements used in these systems. Sucl data have been collected in other countries.

Bukhari and Baloch (3) studied fuel use in tillage and found that the mean diesel fuel consumption for moldboard plowing, disk plowing or disk harrowing in a soil with 4.3% moisture content (wet basis) was higher than that in a soil with 7.9% moisture content (wet basis). Bukhari *et al.* (4) evaluated and compared the performance of a trailed tandem disk harrow and a mounted locally-made implement called Sat-haree in a clay loam soil. They reported that all performance parameters were higher for Sat-haree except travel reduction.

Bowers (2) reported tillage drafts and fuel measurements for 12 soil series and major implements used in North Carolina crop production systems. In his study neasured fuel consumption .for conventional tillage systems ranged from 25.96 to 40.39 l ha^{-1} while for minimum tillage systems it ranged from 20.88 to 28.36 l ha^{-1} . Khalilian *et al.* (9) studied draft and energy use for six reduced tillage treatments on Norfolk loamy sand soil. The results of their work showed that there were not significant differences in fuel consumption rates per shank between subsoiler and paraplow at the same depth of operation and the chisel plow required significantly less fuel rate per shank. Michel *et al.* (11) compared energy requirements of chisel- based and moldboard plow-based tillage system in a fine sandy loam soil for irrigated sugar beets, dry beets, dry beans and corn. They found that chisel-based system produced equal yields with approximately 40% less energy, fuel and time for preplant tillage operations. Chaplin *et al* . (6) determined drawbar and fuel energy use for various tillage operations on loamy sand soil. They found that the reduced tillage system, involving chisel plowing as the primary tillage, used 62%. more drawbar energy than the conventional tillage system.

The amount of fuel and time required for the tillage and planting implements have not previously been documented in Iran. Therefore, a tillage system comparative experiment for wheat production was initiated on a clay loam soil in Isfahan, Iran. The performance parameters for the implements used for similar operations in those tillage systems are reported here.

MATERIALS AND METHODS

A tillage study was initiated in the fall of 1993 on the Kabootarabad Agricultural Research Station located 40 km southeast of Isfahan, on a clay loam soil. Mechanical analysis of the 20 cm suface soil showed that it contains 24% and, 40% silt, and 36% clay. Selected soil properties are shown in Table 1.

Table 1. Selected soil properties.

Depth of soil (cm)	Bulk density (kg m^{-3})	Organic matter (%.)†	Plastic limit (%.)§	Liquid limit (%.)§	Machine capacity (%.)§
0-15	1.41	0.94	18.8	29.3	18.05
15-30	1.43	0.86	¶	¶	19.13

† Organic carbon.

§ Moisture content on dry basis.

¶ Not measured.

Before starting the experiments the previous crop (barley) residues on the conventional tillage, tine-implement (non-inversion) tillage, and till-planting systems plots were burned. At this time, the soil surface was hard. Tillage and planting implements in this study were those utilized to perform the field operations for conventional tillage (including moldboard plowing), tine-implement tillage (including chisel and Khishchee plowing), and till-planting systems for wheat production. Descriptions implement oftter are given in Tables 2 and 3. Khishchee is a machine which is used as a secondary tillage implement in the area (Fig.1). In this experiment, it was used as a primary tillage implement in a reduced tillage system and it was expected to work deeper.

A new two-wheel-drive tractor, Massey Ferguson model MF 285 rated at 53 kW brake power, was used in tillage and planting tests. The tractor weight was 3430 kg, including rear wheel weights and water ballast (without operator's weight). For planting with cultivator combine drill, a hydraulic outlet point for its hydraulic cylinders was needed , hence, a used two-wheel-

Table 2. Tillage implement specifications.

Implement name	Width (m)	Weight (kg)	Description
Moldboard plow	1.20	362	Mounted, 3-bottom, 39-each, general purpose.
Chisel	2.70	380	Mounted, 12 curved shanks mounted on a 2-row toolbar at a spacing of 25cm, 4-cm wide point with a rake angle of 54° attached at the end of each shank.
Khishchee	1.95	194	Mounted, 15 straight rigid shanks, fixed on a 2-row chassis at a spacing of 14-cm with a vertical clearance of 35-cm, a triangular 5-cm wide point with a rake angle of 44° attached at the end of each vertical shank.
Tandem disk harrow (1)	2.08	560	Mounted, 7 plain disks in each gang, diameter of each disk 51 cm, 17.5-cm disk spacing.
Tandem disk harrow (2)	2.41	476	Mounted, 7 disks in each gang, diameter of rear gang plain disk 46 cm, and front gang notched disk 46 cm, disk spacing 18 cm.
Rotary tiller	1.50	404	Mounted, 7-flange, 39-L shaped blades.

drive tractor, John Deere model 2040 rated at 51 kW brake power, was used. Primary tillage operation was performed with the water ballasted tractor, whereas the secondary tillage and planting operations were done without water ballasting. The operational conditions of the tractors are given in Table 4.

Table 3. Planting implement specifications.

Implement name	Width (m)	Unloading weight (kg)	Description
Grain drill	2.50	550	Mounted, 21 sowing rows with 11.9-cm spacing, with fluted-roll metering device, single disk furrow opener and with tine-tooth harrow covering device. (Nordsten Model CLGHI 250).
Cultivator combine drill	2.70	2400	Trailed-type cultivator combine drill with spring release, edge-on tines arranged in 6 rows. Tine spacing between rows 1-2-3, 445 mm and between rows 4-5-6,470 mm. Tine spacing along rows, 540 mm. 15 sowing rows with 18 cm spacing, with studded roller metering device. Seed and fertilizer tubes connected to the 3rd, 4 and 5th row of tine. (The John Shearer Trash Culti Drill)

The experiment was a randomized complete block design with four replications . Seven tillage treatments for wheat production were evaluated. The field operations performed for each of the tillage treatments are shown in Table 5. Experimental plots were 10 m wide by 45 m long with side headlands 6 m wide and main headlands 10 m wide between each block.

The parameters studied were working depth, effective width, speed of operation, wheel slip, fuel consumption, effective machine capacity, field efficiency, and volume of disturbed soil. All tillage and planting performance data were measured and recorded according to the recommendations of RNAM test code and procedure for farm machinery (12).

Table 4. Operational conditions of the tractors.

Implement name	Engine rpm†	Gear	Control setting of hydraulic system
Moldboard plow	1800	4-L§	Draft control
Chisel plow	1800	4-L	Draft control
Khishchee	1800	3-L	Draft control
Disk harrow	1500	1-H¶	Draft control
Rotary tiller	1500	3-L	Float
Grain drill	1000	2-H	Float
Cultivator combine drill	1500	5-H	_

† No load engine setting.

§ Low.

¶ High.

Soil Moisture Content

Gravimetric water content was determined on soil samples collected at 0-10, 10-20 and 20-30 cm depths of each plot immediately before each tillage operation. Two samples per depth increment for each plot were taken

Table 5. Field operations performed for each of the wheat tillage treatments evaluated.

Field operation	Moldboard plow + disk harrow	Chisel plow + disk harrow	Chisel plow + rotary tiller	Chisel plow twice + disk harrow	Khish-chee + disk harrow	Till-plant	No-till
Moldboard plow	x						
Chisel plow		x	x	x			
Chisel plow				x			
Khish- chee					x		
Broadcast granular P&N		x	x	x	x		
Disk harrow	x	x		x	x		
Tractor blade (leveler)	x						
Broadcast granular P&N	x						
Disk harrow	x	x		x	x		
Rotary tiller			x				
Leveler	x	x		x	x		
Grain drill	x	x	x	x	x		
Cultivator combine drill						x	
Cultivator combine drill†							x

† Without cultivator shanks.

effective working width of the primary implements was determined by measuring the width of the 4 to 8 passes of the tilled area and dividing it by the number of passes to get the average effective working width. This measurement was made along four transects 10 m apart in each test plot.

Speed of Operation

The average speed was computed from the time required for the tractor and implement to cover a distance of 35 m. The speed measurement was repeated five times for each replicate.

Wheel Slip

The distance traveled by tractor in 10 revolutions of the drive wheel with no load (dn) and with load (dw) was measured. The wheel slip wascomputed by using the following formula:

$$S = \frac{d_n - d_w}{d_n} (100) \qquad [1]$$

where:

S=wheel slip, %

d_n = distance traveled with no load, m

d_w= distance traveled with load, m.

The distance traveled with no load was measured in the headland along each plot Two to three measurements were made in each plot

Fuel Consumption

The fuel consumption was measured by a fuel meter similar to the one described by Maasumi (10). The fuel meter was installed on the MF 285 tractor. The fuel consumption for the cultivator combine drill was determined by filling the fuel tank of John Deere 2040 tractor to capacity before testing the machine in the test plot. After planting the total area of the test plot, the fuel tank of the tractor was refilled to the same fuel level with a 1000 ml graduated cylinder. The total quanity of the fuel needed to refill the tractor fuel tank up to the same mark was recorded. The fuel consumption per hectare was computed.

Field Efficiency and Effective Machine Capacity

The field efficiency and effective machine capacity were determined by tilling or planting an area of 45 m long and 10 m wide for each implement. The field efficiency was calculated by using the following equation (5):

$$\text{Field efficiency} = \frac{\text{Time spent actually in work}}{\text{Total time spent}} (100) \qquad [2]$$

The effective machine capacity was calculated by using the equation:

$$C = \frac{A}{T_t} \qquad [3]$$

Where:

C= effective machine capacity, ha h^{-1}.

A= area tilled or planted, ha.

T_t= total time spent, h.

Volume of Soil Disturbance

The volume soil disturbed of in primary tillage operations was calculated by using the following eauation (12):

$$V = 10000\ Cd \qquad [4]$$

Where:

V= soil volume disturbed, m^3 h^{-1}.

C= effective machine capacity, ha h^{-1}.

d= the average depth of operation, m..

Field test for the tillage and planting measurements consisted of two stages. First, a practical area was used to set and adjust the operational depth of the tillage or planting implement and to determine the gear selection and engine speed that would provide a manageable high ground speed at a reasonable load matching of the implement and tractor. For primary tillage operations the tractor was operated at nearly maximum power. The chisel plow tine spacing was adjusted so that the space between the adjacent tines would be disturbed. The shield on the rotary tiller was completely lowered in order to obtain maximum shattering and the rotor speed was adjusted with regulating the engine speed to break the clods without producing too much dust. To get the maximum possible operating depth on the rotary tiller, the gauge shoes on the machine were removed. The second stage consisted of conducting the tillage or planting tests and collecting data.

A completely randomized design was used to analyze the performance parameters of the implements in similar operations of the tillage systems. We averaged several measurements of soil moisture cotent, depth and width of work, forward speed and slip on each plot before the analysis of variance was performed. Therefore , the results in Tables 6 through 11 are reported in terms of the mean and the standard deviation of those values.

RESULTS AND DISCUSSION

Time, fuel requirement and work rate measurements were compared according to implement. The results given in the data tables are in terms of mean and standard deviation of the averaged values of plots for each parameter in similar tillage or planting operation tests. The standard deviation estimates are given to indicate the range observed. The variability can be attributed to many factors including soil moisture, soil density, and operation speed and depth.

Performance results of primary tillage implement tests are given in Tables 6 and 7. Soil moisture values are the means of readings in two depth increments of 0 - 10 and 10 - 20 cm for all replications of similar operations. There were no significant differences among the experimental plots for similar operations or among the plots for different primary tillage operations. These results imply that the moisture content of the experimental plots were quite uniform. Average soil moisture was 10.74% on dry weight basis. For this particular soil, plastic limit occurred at 18.8% moisture and liquid limit occurred at 29.3% moisture (dry weight basis); therefore, the 10.74% moisture level represents a dry, high strength soil condition.

Effective width, operating depth , forward travel speed and wheel slip for primary tillage operations are given in Table 6. The effective widths of moldboard plow and Khishchee were similar to their nominal widths. However, the effective width of the chisel plow was less than its nominal width. This was due to the overlapping of consecutive passes of this machine.

Forward travel speed and wheel slip were significantly different for moldboard and chisel plow and Khishchee. Slower travel speed and higher wheel slip for the chisel plow occurred because the effective width of the chisel plow was twice that of the moldboard plow. This causes a greater disturbed volume of soil, with a resulting higher draft which the tractor should provide. The Khishchee loosened the soil more vigorously, which required a large draft force, thus high wheel slip occurred. As the large draft force produced the large torque of the transmission system, the lower gear was selected to bear the torque.

Table 6. Comparison of primary tillage implements performance results.

Soil moisture @ 0-20 cm (%.)[†]	Std. dev.[§]	Implement name	Effective width (m)	Std. dev.	Operating depth (cm)	Std. dev.	Forward speed (km h^{-1})	Std. dev.	wheel slip (%)	Std. dev.
11.20a*	3.68	Mold-board plow	1.203	.021	20.6a	2.47	5.47a	.103	5.25a	0.27
10.99a	2.77	Chisel plow	2.39	.068	19.35a	1.98	4.89b	0.12	20.67b	2.37
10.04a	2.37	Khishchee	2.09	.02	14.85b	1.27	3.35c	.017	29.5c	0.21

* Means followed by the same letter in each column are not significantly different according to Duncan's new multiple range test at the 5% level of probability.

† Moisture content on dry basis.

§ Standard deviation.

Implement test results for fuel consumption, effective machine capacity, field efficiency and volume of disturbed soil for primary tillage operations are given in Table 7. The reported fuel consumptions represent measured values for the applied implement loading, tractive efficiency, and tractor engine/power train operating conditions. Therefore, the measured fuel consumptions are estimates of fuel requirements.

Fuel requirement among primary tillage implements showed significant differences between Khishchee and moldboard or chisel plow. The numerically highest fuel requirement was measured for the khishchee which is probably related to higher wheel slip and slower forward speed. This is also due to closer shank spacing on this machine which produces more broadcast loosening.

Khishchee is a machine which is used as a secondary tillage implement in the area (Fig. 1). In this experiment, it was used as a primary tillage

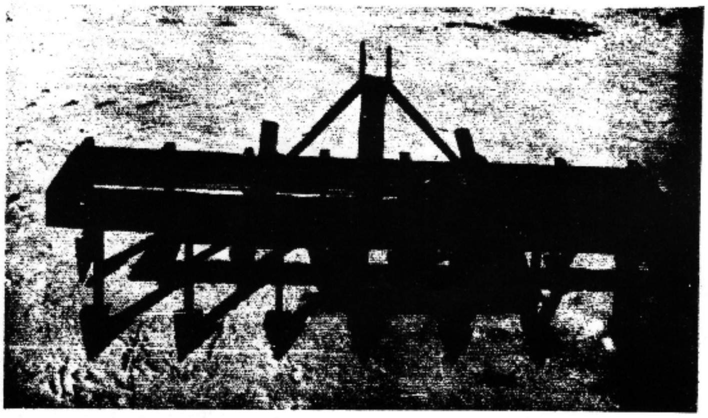

Fig. 1. Khishchee.

Table 7. Fuel measurements and work rates of primary tillage implement tests.

Implement name	Fuel consumption ($l\ ha^{-1}$)	Std. dev.[†]	Machine capacity ($ha\ h^{-1}$)	Std. dev.	Field efficiency (%)	Std. dev	Disturbed soil volume ($m^3\ h^{-1}$)	Std. dev.
Moldboard plow	11.94a*	1.05	0.517a	0.074	70.90a	2.18	1078.50a	179.5
Chisel plow	11.84a	0.82	0.743b	0.071	63.37b	4.90	1408.44b	177.3
Khishchee	30.60b	3.68	0.455a	0.007	70.40a	0.99	676.35c	68.1

* Means followed by the same letter in each column are not significantly different according to Duncan's new multiple range test at the 5% level of probability.

† Standard deviation.

implement in a reduced tillage system and it was expected to work deeper. Because of forward rake angle of Khishches point and small vertical clearance between the point and chassis and small spacing between its shanks, the soil was upheaving under the chassis. The upcoming soil which was caught under the chassis interfered with the failure boundary of the point and therefore, acted as a surcharge on the soil surface. Based on Coulomb's soil strength relationship , a high surface surcharge increases the shearing resistance offered by the lower soil layers as they attempt to deform or fail upward (13).Hence, the tractor, hence, was slowed down (high slip) in order to provide enough traction for pulling the implement through the soil. Although, the draft control system of the tractor automatically and sometimes the operator deliberately were reducing the depth, but the high confining pressure exerted by the soil caught under the chassis caused higher slip and slower forward speed. Hence, the fuel consumption was quite high.

The fuel consumption for moldboard plow with 20.6 cm depth of cut operating at speed of 5.47 km h^{-1} was 11.94 l ha^{-1} at 10.74% soil moisture content (dry weight basis). For similar soil texture (Cecil clay loam), fuel requirement for moldboard plowing with 25.4 cm depth of cut operating at a speed of 6.41 km h^{-1} was reported to be 13.66 l ha^{-1} at 16.32% soil moisture content (dry weight basis),(1). Therefore, with respect to the differences between the forward speeds,depths of cut and the soil moisture contents in the two conditions, the measured fuel consumption in this work seems reasonable.

There was no significant differences at($P< 0.05$) in fuel requirements between moldboard plow with 1.20 m effective width of cut and chisel plow with 2.40 m effective width of cut. This is due to the fact that the moldboard plow in addition to cutting and breaking the soil, inverts the soil as well, whereas the chisel plow only loosens the soil.

Machine capacity and field efficiency among primary tillage implements showed significant differences between the chisel and moldboard plow or Khishchee. The chisel plow had significantly higher plowed area per hour. Its forward travel speed and field efficiency were significantly lower than those of the moldboard plow, but this was due to larger width of cut on the chisel plow which produces higher work rate.

The chisel plow had significantly lower machine efficiency. This was because the working width of this machine is wider than the overall width of the tractor which causes the operator to take a larger turning radius or using the reverse gear on the headlands for consecutive rounds.

The volume of disturbed soil per hour showed significant differences at P(<0.05) among the primary tillage implements. The numerically highest volume of the disturbed soil per hour was calculated for the chisel plow, which was probably related to its higher machine capacity and operating.depth The lowest volume of disturbed soil per hour was calculated for the Khishchee, but this implement did not till as deeply and had a lower machine capacity. The value for the moldboard plow was significantly lower than that for the chisel plow which was probably due to lower machine capacity of the moldboard plow.

Forward speed, fuel consumption, machine capacity and field efficiency for secondary tillage operations are given in Table 8. Soil moisture values are the means of reading in 0 to 10 cm depth for all repetitions of similar operations. There were no statistically significant differences among the experimental plots for similar operations or among the plots for different secondary tillage operations. These results imply that the moisture content of experimental plots were quite uniform.

Although disking after chisel plowing twice and disking after moldboard plowing once tends to show more fuel consumption, no statistically significant difference was found between the disking. Prior tillage operations

Table 8. Comparison of secondary tillage implement performance results.

Soil moisture @ 0-10 cm (%.)†	Std. dev.§	Implement name	Forward speed (km h^{-1})	Std. dev.	Fuel consumption (l ha^{-1})	Std. dev.	Machine capacity (ha h^{-1})	Std. dev.	Field efficiency (%)	Std. dev.
5.07a*	0.82	Disk harrow(1)¶ (after moldboard polw)	6.4a	0.34	6.73a	0.90	0.78a	.047	66.2a	3.1
6.48a	1.17	Disk harrow(2)¶ (after chisel polw)	6.65a	0.20	5.85a	0.64	0.84a	.078	65.67a	2.55
5.28a	1.45	Disk harrow (2) (after chisel plow twice)	6.12a	0.20	6.88a	0.58	0.85a	.042	68.1a	3.39
4.85a	0.52	Disk harrow (2) (after Khishchee)	6.50a	0.16	6.43a	0.35	0.83a	.021	67.2a	1.8
††	††	Disk harrow (2) (after disk harrow (2))	6.44a	0.17	6.51a	0.67	0.86a	.038	66.1a	3.44
6.05a	1.7	Rotary tiller§§ (after chisel plow)	3.65b	.033	10.66b	2.60	0.42b	.037	71a	2.45

* Means followed by the same letter in each column are not significantly different according to Duncan's new multiple range test at the 5% level of probability.

† Moisture content on dry basis.

§ Standard deviation.

¶ Depth of cut was about 10 cm.

†† Not measured.

§§ Depth of cut was about 6 cm.

could influence fuel consumption mainly due to tractive efficiency changes. Therefore, it seems that the traction conditions were similar for all disking operations.

Prior tillage operations had no significant influence on measured values of disking parameters. Thus, values for all parameters could be averaged across prior tillage operations (Table 9). The disk harrow with 2.08m working width and 10 cm depth of cut operating at a speed of 6.42 km h^{-1} consumed 5.49 l ha^{-1} of fuel. The rotary tiller with 1.50 m working width and 6 cm depth of cut operating at a speed of 3.65 km h^{-1} consumed 10.66 l ha^{-1} Hence ,in secondary tillage operations, rotary tilling had the lowest machine capacity and the highest fuel consumption. Rotary cultivators have higher specific power requirement. It means they require more power for a given volume of disturbed soil.The power used for acceleration of the soil particles, which mostly is lost for cultivation purposes, is much higher than draft implement (7) .The low value of machine capacity of rotary tiller was due to the lower forward velocity of the tractor and the narrower width of the implement.

The grain drill was used in all moldboard plow, chiselplow, Khishchee-based tillage systems. The cultivator combine drill was used in the till-plant system and it, therefore, worked in untilled soil. The performance factors required to operate each of the two planting implements in different tillage systems are summarized in Table 10. The measured values for all parameters for planting with the grain drill could be averaged across prior secondary tillage operations on the basis of the non significant variation due to prior tillage operation.

Differences in forward speed, fuel consumption, machine capacity and field efficiency between the grain drill and the cultivator combine drill were significant due to the soil conditions before planting (tilled or untilled soil) and planting implement type (Table 11). Realistic working efficiency was

Table 9. Summary of secondary tillage performance results.

Soil moisture @ 0-10 cm (%.)†	Std. dev.§	Implement name	Forward speed (km h^{-1})	Std. dev.	Fuel consumption (l ha^{-1})	Std. dev.	machine capacity (ha h^{-1})	Std. dev.	Field efficiency (%)	Std. dev.
5.46a*	1.17	Disk harrow	6.42a	0.25	6.54a	0.65	0.84a	0.05	66.6a	2.93
6.05a	1.70	Rotary tiller	3.65b	0.03	10.66b	2.59	0.41b	0.04	71a	2.54

* Means followed by the same letter in each column are not significantly different according at the 5% level of probability to Duncan's new multiple range test.

† Moisture content on dry basis.

§ Standard deviation.

Table 10. Comparison of planting implement performance results.

Soil moisture @ 0-10 cm (%.)†	Std. dev.§	Implement name	Forward speed (km h^{-1})	Std. dev.	Fuel consumption (l ha^{-1})	Std. dev.	machine capacity (ha h^{-1})	Std. dev.	Field efficiency (%)	Std. dev.
¶	¶	Grain drill†† (after disking)	6.48a*	0.28	3.08a	0.54	0.88a	0.13	60.00	9.15
¶	¶	Grain drill (after rotary tilling)	6.18a	0.29	3.08a	0.08	0.86a	0.13	59.53a	8.12
6.38	1.54	Cultivator combine drill§§	4.95b	0.48	5.82b	0.26	0.42b	0.11	24.20b	3.92

* Means followed by the same letter in each column are not significantly different at the 5% level of probability.according to Duncan's new multiple range test.

† Moisture content on dry basis.

§ Standard deviation.

¶ Not measured.

†† Planting depth was 3-4 cm.

§§ Operating depth was about 7.5-8.5 cm.

Table 11. Summary of planting implement performance results.

Soil moisture @ 0-10 cm (%)†	Std. dev.§	Implement name	Forward speed (km h^{-1})	Std. dev.	Fuel consumption (l ha^{-1})	Std. dev.	machine capacity (ha h^{-1})	Std. dev.	Field efficiency (%)	Std. dev.
¶	¶	Grain drill††	6.42*	0.30	3.08a	0.50	0.88a	0.13	59.9a	8.75
6.38	1.54	Cultivator combine drill§§	4.95b	0.48	5.82b	0.26	0.42b	0.11	24.2b	3.92

* Means followed by the same letter in each column are not significantly different at the 5% level of probability according to Duncan's new multiple range test.

† Moisture content on dry basis.

§ Standard deviation.

¶ Not measured.

†† Planting depth was 3-4 cm.

§§ Operating depth was about 7.5-8.5 cm.

difficult to achieve with cultivator combine drill because of plot and headland limitations and great lenght of the machine-tractor combination which caused a significant increase in turning time. The tractor had to be stopped and reversed before completing a turn in the headlands. Hunt (8) states that long fields, quick turns, wide machines and fast speeds all contribute to high machine capacity. Therefore, low machine capacity for cultivator combine drill was due to low forward speed, slow turns and short field.

CONCLUSIONS

1. The average measured fuel consumptions were the same for both chisel and moldboard plowing but the machine capacity of the chisel plowing was about forty % more than that of moldboard plowing . Hence, if the soil inversion is not required, chisel plowing with a high machine capacity can be performed .

2. Of the three primary tillage operations considered, plowing with Khishchee had the highest fuel consumption and the lowest machine capacity. To use this machine as an efficient primary tillage implement, its working depth should be decreased or the vertical clearance under the chassis should be increased by using longer shanks

3. In comparing the performance of the rotary till and the disk harrow, the machine capacity of the rotary tiller was one half with a 63% higher fuel requirement.

4. In comparing the performance of the grain drill working in the tilled soil and the cultivator combine drill, as a till-planting machine working in the untilled soil, the fuel consumption of the grain drill was about one half with twice the machine capacity.

ACKNOWLEDGEMENTS

The authors wish to express their thanks to Agricultural Engineering Research Institute for financial support, and to Mr. A. Maassumi and O. Taki for helping them in conducting the field experiments.

LITERATURE CITED

1. Bowers, C.G., Jr., 1985. Southeastern tillage energy data and recommended reporting. Trans. ASAE 28: 731-737.
2. Bowers, C.G.Jr., 1989. Tillage draft and energy measurements for twelve southeastern soil series. Trans. ASAE 32: 1492-1502.
3. Bukhari, S., and J.M. Baloch. 1982. Fuel consumption of tillage implements. AMA 13: 20-22.
4. Bukhari, S., J.M. Baloch and A.N. Mirani. 1992. Comparative performance of disk harrow and sat haree. AMA 23:9-14.
5. Butterworth, B. and J. Nix. 1983. Farm Mechanisation for Profit. Granada Publishing, England. 269 p.
6. Chaplin, J., C. Jenane and M. Lueders.1988. Drawbar energy use for tillage operations on loamy sand. Trans. ASAE 31:1692-1694.
7. Davies, B.,D. Eagle and B. Finney. 1986. Soil Management.Farming Press Limited, England. 287 p.
8. Hunt, D., 1979. Farm Power and Machinery Management. Iowa State University Press, Ames, Iowa.,USA. 365 p.

9. Khalilian, A, T.H. Garnee, H.L. Musen, R.B. Dodd and S.A. Hale. 1988. Energy for conservation tillage in Coastal Plain soils. Trans. ASAE 31: 1333-1337.

10. Maasumi, A. 1993. Evaluation of traction performance of two common tractors in Iran. M.S. Thesis. Shiraz University, Shiraz, Iran.

11. Michel, J.A., Jr K.J. Fornstrom and J. Borrelli. 1985. Energy requirements of two tillage systems for irrigated sugar beets, dry beans and corn. Trans. ASAE 28: 1731-1735.

12. Regional Network for Agricultural Machinery. 1983. RNAM Test Codes and Procedures of Farm Machinery. Technical Series No. 12. Bangkok, Thailand. 291 p.

13. Spoor, G. and R.J. Godwin. 1979. Soil deformation and shear strength characteristics of some clay soils at different moisture contents. J. Soil Sci. 30:483-498.