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Full Length Research Paper

A study on the chopping and mixing of cotton stalks with soil

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This study examined the methods adopted in Turkey to remove cotton stalks remaining in the field after the cotton harvest and quantified the efficiency of different mechanized stalk choppers. In this study, the performance of three different types of cotton stalk choppers was assessed (chain-type, splined-type and vertical-blade rotating dredge). Field experiments were conducted with each type to determine the proportion of non-uprooted cotton stalks; mean "post-chopping height" of the stalks, measured from soil surface; and the frequency distribution of the piece length of the stalks scattered around the field or mixed with soil after chopping. In addition, the workforce requirement, using time and fuel consumption of each type of chopper was calculated. The lowest fuel consumption was recorded by the chain-type stalk chopper (5.0 l/da), while the highest fuel consumption was recorded by the vertical-blade rotating dredge (7.1 l/ha). The largest "mean post-chopping piece size" was achieved by the vertical-blade rotating dredge plus geared cylinder (28.36 cm), while the smallest size was recorded by the splined-type stalk chopper (13.38 cm). The highest rate of stalks mixed with the soil after chopping was achieved by the splined-type stalk copper (92.5%).

Key words: Cotton, stalk, chopping, stalk chopper.

INTRODUCTION

Within Turkey, cotton is cultivated mostly in the Aegean, Mediterranean and South Eastern Regions. While the extent of cotton cultivation in Turkey varies annually, the average annual cultivation area is approximately 650 thousand hectares. Approximately, 928 thousand tons of fiber was produced in 2004. Turkey meets 2% of the world production of 20 million tons and is the 7th largest cotton producer in the world (Anonymous, 1988). Approximately, 400,000 rural families in Turkey are involved in the cultivation of cotton, illustrating the economic and social significance of this crop. Cotton is grown in four main regions including Southeastern Anatolia, Cukurova, Aegean and Antalya (Polat et al., 2006).

Cotton production comprises approximately, 91% of the area of fiber plants globally (FAO, 2008). Within Turkey, cotton accounts for 98.9% (384,000 ha) of fiber plant coverage. Cotton is one of the most important industrial crops of the Southeast Anatolia Region of Turkey. Cotton sowing area and fiber production have increased significantly because of increase in irrigated lands following the GAP (Southeastern Anatolia Project). Cotton production consists of different phases, from seed sowing to ginning. One of these phases is the cotton harvest (Copur et al., 2010). Crop residues remaining in the field after the harvest are removed by burning the stubble or leaving the stalks on the field surface, to be mixed with soil either directly or by mechanized chopping. This depends on stalk type, climatic conditions, agricultural methods and level of usage of the chopper; as in the case with some other field crops (sunflower, corn, cereals, paddy, etc), no systematic approach is adopted to utilize the cotton stalks remaining in the field after the harvest. These stalks are generally collected by farmers or mixed into the soil after the field is ploughed with a tractor plough, without any stalk chopping process. Bigger and thicker stalks of industrial plants like sunflower, cotton, corn etc, cause some problems during tillage and planting. Besides, stems remain on the surface of the field as the stem and stalk are not executed to destructive force

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during harvest of these plants. Therefore, stalks should be chopped with extra processing for preparing next growing season. Chopping process has been done by heavy duty disc harrow as a conventional method and recently machines with rotary types. A number of researches have been carried out on chopping by disc harrow (Gonulol et al., 2009).

A survey was carried out to identify the methods used by farmers to remove stalks remaining in the field after the harvest. The results indicated that 75.6% of cotton producers in the study use 3 or 5-furrow ploughs, which bring cotton stalks to the surface, facilitating manual removal by workers. The remainder (24.4%) use some form of mechanized stalk chopper to remove the cotton stalks. Within this group, 18.3% use developed stalk choppers, 76.2% use chain-type stalk choppers and 5.5% use a rototiller or milling machine after field is ploughed (Polat and Kaplan, 2008).

Cotton is generally cultivated for cotton fiber and cotton seed. However, cotton stalks that remain in the field after the harvest can also be used for some purposes. Thanks to its woody, fibrous structure, cotton stalk is particularly suited for use as a fuel and in the paper and particle board industries (Gursoy, 2002). Under Turkish growing conditions, this important by-product (which is not yet utilized economically in Turkey) may produce a dry stalk yield between 300 - 800 kg/da (Evcim and Yumak, 1998). Many previous researchers have reported that incurporating plant residues into soil reduces the risk of soil erosion. The more plant residues are left on the field surface, the more resistant the field becomes to surface water flows and erosion. The use of plant residues on the field surface is the most important component of many erosion control methods. The amount of the plant residue required to control erosion varies, depending on the post-harvest residue amount, grazing and the method applied in processing and cultivation of the soil (Burr and Shelton, 2001). Retaining 20% plant residue on the surface after ploughing reduces erosion by 50%, while 80% plant residue reduces erosion by 90% (Dickey et al., 1986). Taking into consideration the extent of cotton cultivation in Turkey, 3.2 million tons of cotton stalks is estimated to be produced annually. Of the potential uses of cotton stalks (discussed above), the only one widely used is that of fuel. This is mainly due to the lack of mechanized facilities required to transfer the stalks from the field to locations where they might be put to other uses. Another reason is the belief amongst producers that mixing of stalks into soil increases the productivity of the field. Gursoy (2002) found that most farmers are prepared to pay for the removal of the stalks from the field after the harvest. Where cotton stalks are mechanically chopped and integrated into the soil, 48% of the nitrogen, 41% of the phosphor and 74% of the potassium taken from the soil by the cotton plant is returned to the soil (Basoglu, 1964). Chopping and mixing of cotton stalks with soil provides each da. of soil with 6.3 kg nitrogen, 2.5 kg phosphor and 6.2 kg potassium, which corresponds to 31 kg ammonium sulfate, 16 kg super phosphate and 3 kg potassium sulfate fertilizer of the nutrient (Aydemir, 1982).

Leaving the unprocessed cotton stalks in the field causes problems in soil processing and cultivation during the following growing season. Plant residues, particularly those which are not properly chopped or mixed with soil, can negatively affect the cultivation processes and germination performance. In recent years, finding the workforce required for the cotton harvest and removal of the stalks from the fields has become a problem in Turkey. The level of mechanization in cotton production -from processing of soil to harvest- is gradually increasing within the region. After the harvest, cotton stalks have to be removed, chopped or mixed with soil in a manner that does not affect the operation of the agricultural machines, so that the mechanization processes of the next crop cultivation can be performed easily and smoothly. Cotton stalks are difficult to remove or chop and there is only limited mechanization for the mixing of these stalks into soil. Thus, this study aimed to identify how farmers solve the problem of removing cotton stalks from fields after the harvest and to compare the performance of three different types of machine used to chop or mix the cotton stalks into the soil.

MATERIALS AND METHODS

Material

Experiment field and plant material

A face-to-face questionnaire (n = 52) was conducted with farmers living in the Southeastern Anatolia Region of Turkey. Cotton producers were asked about the total area of their agricultural fields and the fields they use for cotton production, as well as the methods they use to remove cotton stalks. Stonville-453 cotton species was used in the present study. The cultivation of this species has increased considerably with the start of agricultural irrigation of the Sanliurfa-Harran Plain as part of the GAP (South-eastern Anatolia Project). Experiments on the chopping of cotton stalks were conducted on plants produced at the Faculty of Agriculture, Harran University. Cotton produced in the experiment fields was harvested by hand at two times: September and October. Field experiments were conducted in November and December of 2006 and 2007, after the cotton harvest had finished.

Stoneville-453

In the U.S., Stoneville Pedigreed Seed Co. developed and is registered in 1988. It can be moderately sized; mid-width and center frequency and leaves are hairy. Woods is 2 - 3 branches. It is described in pyramid form and is medium early. Cocoon is medium sized, oval or slightly round and is billed. Sowing and the average number of days until the boll opening is 120. Ginning is 41.9%, 29.3 mm fiber length, fiber fineness 3.84 micronaire, fiber strength of 28 - 30 g / tex, 100 seed weight 9.4 and 5.6 g boll weight. Our region, in 1995,

Figure 1. Splined-type stalk chopper.

received the certificate and is widely produced.

Experimental equipment

A second-indicator digital chronometer was used in the field experiments to measure the chopping success of three different choppers. A digital-indicator caliper (± 0.01 mm sensitivity) and a micrometer were used to measure the diameter and length of cotton stalks. A 100 cm ruler and a tape-rule were used to measure the height of stalks. A New Holland TD95D-model, two-wheel drive cab-tractor belonging to the Faculty of Agriculture, Harran University was used in the field experiments. The vehicle was 5,700 kg in weight and had a power take-off cycle of 540-1,000 d/d. Three different types of stalk choppers were used in this study. General information and technical features of the choppers are listed below.

Splined-type stalk chopper

The first stalk chopper used in the experiments was the splined-type stalk chopper produced by Sönmezler Tarim Makineleri Co. The machine is connected to the tractor via two-grade crusher equipment and a hang-type joint (Figure 1). The framework of the Three Point Hanger Equipment was made of rectangular profile material. In case the machine makes a vertical move during operation, the articulated joint -to which the mid-arm is connected- stabilizes the tractor to prevent the machine from leaning forward. The machine is activated by tractor power take-off. A shaft transfers the motion from the power take-off to the gearbox of the stalk chopper. The motion coming from tractor take-off and entering into gearbox at 540 d/d increases by 2.72. The input to the gearbox of the chopper is transformed at 90°C and is transferred via a shaft joint to the shaft of a belt-pulley mechanism. Belts in the belt-pulley mechanism have a geared holding surface. The motion of the belt-pulley mechanism is transferred to a shaft which holds moves and directs the chopper blades. The chopper is equipped with a two-grade crusher unit, high-inertia type blades and on-board double-line fixed blades. Shutter plates of 6 mm thickness are placed on the front part of the chopper. Hammer-type blades are used in this type of stalk chopper (Figure 2). The chopper contains 32 hammer-type blades. The work width of the machine is 3.200 mm.

Chained-type stalk chopper

The chained-type stalk chopper is hung behind the tractor used for cotton harvesting (Figure 3). The chopper -which works according to the free cut principle- is activated by the power take-off. The motion transferred from the power take-off via a shaft changes direction with the help of an on-board ring gear. The machine consists of a vertical iron shaft -11 mm in thickness, 50 mm in width and 300 mm in length, and; a chain mechanism that can be attached to this iron shaft, both below it and along its' vertical length. This chain mechanism rotating at 540 d/d chops the stalks. The cutting area is surrounded by a plate which is 300 mm in height and 3 mm in thickness. This plate is mounted to prevent scattering of the chopped stalks, so as to prevent any damage to the driver or the tractor. This machine -which is also known locally as “cotton stalk gin” - can chop the cotton stalks in two lines simultaneously. The efficient work width of the machine is 1.230 mm.

Vertical-blade rotating dredge

The vertical-blade rotating dredge used in the present study was

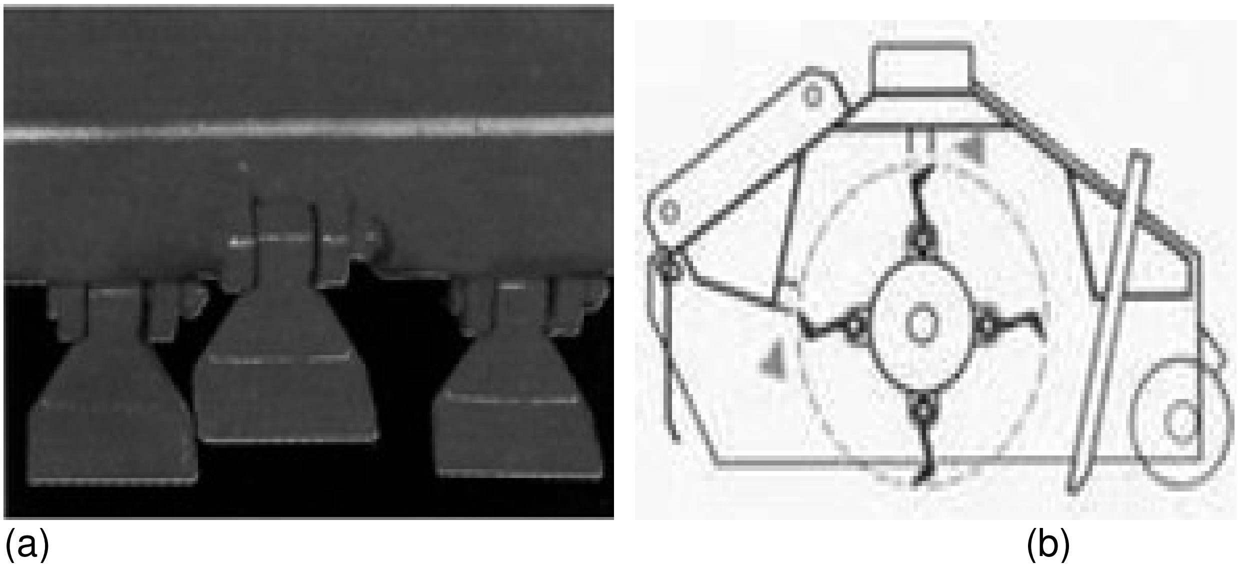

Figure 2. Hammer-type blades of the splined-type stalk chopper.

Figure 3. Chained-type stalk chopper.

produced by Sonmezler Tarim Makinalari Co. (Figure 4). It is composed of two parts. The first part consists of the rotors driven by the power take-off of the tractor and vertical blades (Figure 5a). The motion is transferred to the blades via a rotor gearbox. Rotor shafts are made of forged steel in one piece. Due to the pressure applied from above and below, the rotors also function as a bearing.

Figure 4. Vertical-blade rotating dredge.

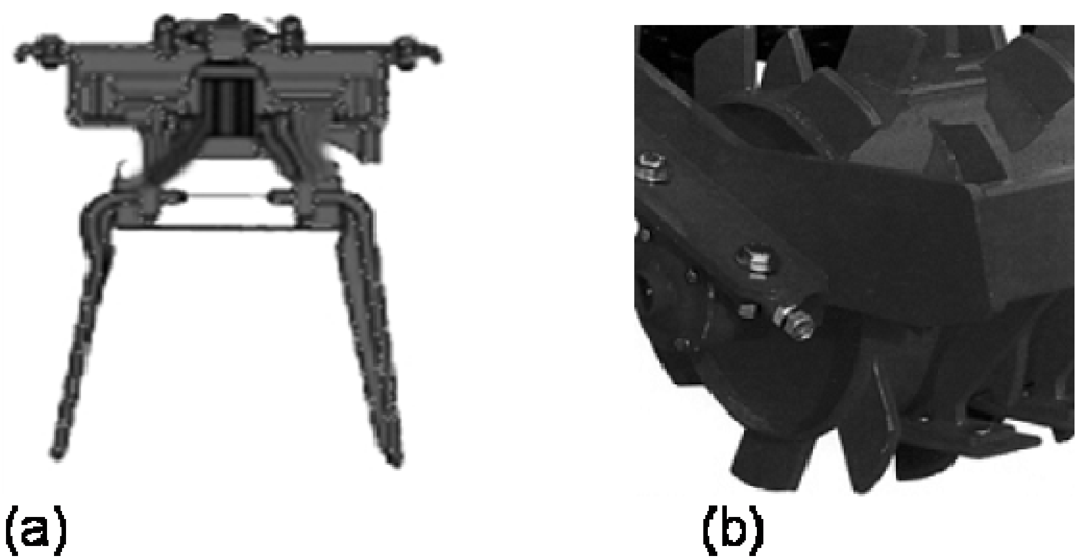

Figure 5. Blades and cylinder gears of vertical-blade rotating dredge

Blades are made of steel produced by mixing manganese with silisium. The blades move towards the soil by rotating cyclically in a horizontal direction. The second part of the machine consists of a cylinder mounted on the back of the machine (Figure 5b). The cylinder consists of long gears which are ordered in sequence. A cleaning mechanism located between the gears prevents the

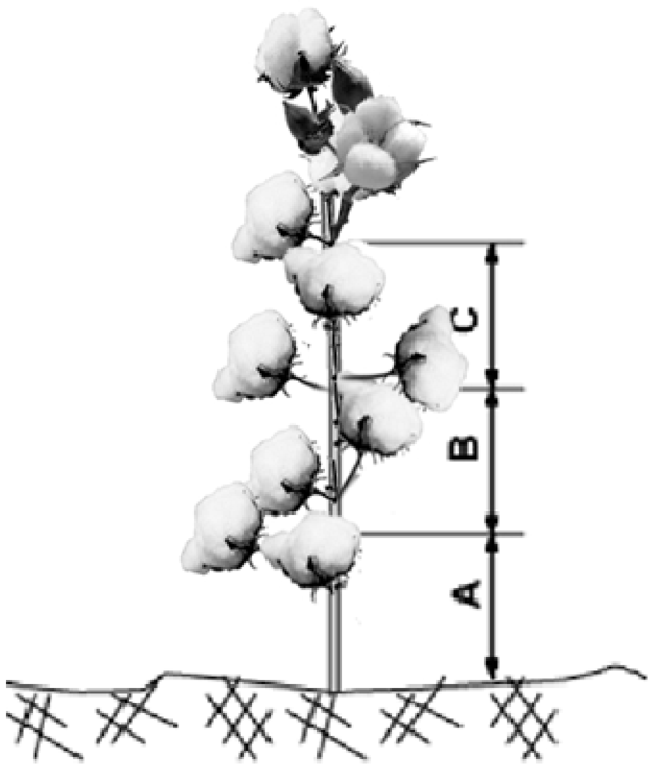

Figure 6. Stalk parts subjected to measurement.

cylinder from becoming choked. These soil scrapers which clean the cylinder are located under the profile, which forms the framework of the cylinder, with a wide angle. The diameter and the active work width of the cylinder are 480 and 3,000 mm, respectively.

Measurement of stalk length and thickness before chopping

The heights of the cotton stalks remaining in the field after the harvest were measured from the soil to the tip. In addition, the thickness of these stalks was measured, by taking the collar as the basis, at three different points (A [0 - 10 cm], B [10 - 20 cm] and C [20 - 30 cm]) along the vertical length (Figure 6). Measurements started with the cotton stalks in the center of the field and continued with the cotton stalks in each line in both directions (each line is 1 m away from the other line).

Detection of stalk density

Following cultivation, plants can potentially be removed during maintenance works such as thinning, weeding and irrigation. Thus, the post-cultivation plant population can differ from the post-harvest plant population. Therefore, plants falling within one of the 10 randomly-selected sample areas (each 1 m^2) were counted, in order to estimate the plant population of the experiment field. Following counting, the stalk amount/unit area was calculated by using the equation below (Kocabıyık, 2003; Hickman and Schoenberger, 1989; Lyon, 1998; Nielsen and Aiken, 1998).

$$Qn = (1000 \times n) / b$$

Where Qn = stalk density (unit/da), n = number of stalks in 1-m line (unit), and b = distance between two lines (m).

Field experiments

Establishment of experiment pattern

The field experiments assessed the efficiency of 3 different types of stalk chopping machine. The experiment used a Divided Lots Test Pattern, with the aim of accounting for the variation that can result from the structure of the cotton stalks and the field (Kocabıyık, 2003; Duzgunes et al., 1983; Shelton et al., 1994). The size of each lot was chosen as 5 x 25 m (Figure 7). The "TARIST" statistical program was used to analyze the data obtained during the experiments and a "LSD" test was applied to compare the means of the parameters that were shown to be important (Acikgoz et al., 1994).

Post-chopping measurements

The size of the stalks which remained in the field after the copping process was deemed as the most important data in terms of the success of the stalk chopping process. Three areas (1 m^2) were randomly selected from each parcel in the experiment field. For each area selected, stalk pieces on the surface and those mixed with soil were collected, counted and their length was measured (Kocabıyık, 2003). Measurement values and the efficiency of the stalk choppers were calculated by using the equation below (Duzgunes et al., 1983).

$$\chi_{ort} = \left(\sum f_i \times \chi_i \right) / \sum f$$

Where χ_{ort} = mean height of chopped stalks (mm), χ_i = mean height of group stalks (mm), f_i = number of pieces measured (for each group) (frequency) (ea), and f = total number of pieces (total frequency) (ea).

The efficiency of the 3 different stalk choppers was calculated for cotton stalk/unit length, based on the stalk sizes, measured both before and after the chopping process. An area (1 m^2) was randomly selected from each parcel to calculate the density of the stalks which remained on the field surface after the chopping process. The pieces of the cotton stalks within these areas were counted individually. The rate of subsidence of the stalks was only calculated for the experiments which used a combination of two machines. To learn whether or not the under-soil parts of the stalks were chopped, 1 m^2 area was randomly selected from each parcel and the number of roots in these areas was counted to calculate the "root chopping" percentage of the choppers.

Determination of the basic performance values of the choppers

Detection of fuel consumption values

The fuel consumption of the tractor used to pull the choppers was calculated to determine the effect of each of the chopping machines upon performance and economy. The fuel tank of the tractor was filled completely before entering each parcel. At the end of the parcel, the fuel tank was re-filled completely; thus, the fuel consumption/parcel of the tractor was calculated. A measuring cap was used to fill the fuel tank. The following equation was used to calculate the fuel consumption/parcel.

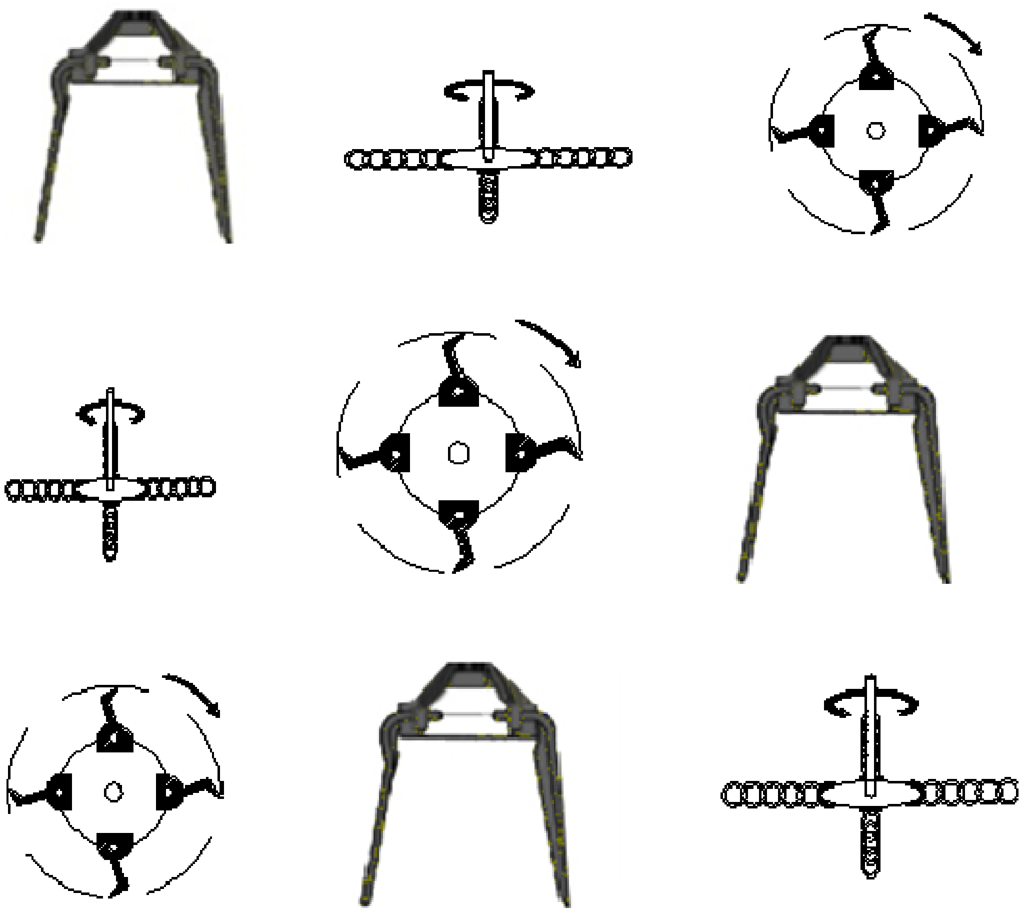

Figure 7. Experiment pattern.

$$YT = TY/A$$

Where YT = fuel consumption (l/da), TY = amount of the fuel consumed for each parcel (l), and A = size of the parcel (da).

Calculation of working capacity

A chronometer was used to calculate the time required for each chopper to reach the end of a parcel in one pass. Moreover, the total time each chopper required to complete the whole parcel was calculated. From the time measurements, working speed was calculated for each parcel using the following equation (Kocabıyık, 2003; Ulger et al., 2002).

$$V = L/t$$

Where V = working speed (m/s), L = distance traveled (m), and t = time (s).

After calculating the working speed of the tractor, effective work success, theoretical work success and field success of the three stalk choppers were calculated (Kocabıyık, 2003; Kayişoglu, 1993);

$$E.W.S = A/T$$

Where E.W.S = effective work success (da/h), A = size of the lot (da), and T = total processing time (h).

$$T.W.S = 3.6 \times B \times V$$

Where T.W.S = theoretical work success (da/h), B = work width of the chopper (m), and V = mean working speed of chopper (m/s).

$$F.E = (E.W.S / T.W.S) \times 100$$

Where F.E = field efficiency (%), E.I.B = effective work success (da/h), and T.I.B = theoretical work success (da/h).

RESULTS AND DISCUSSION

Physical characteristics of the cotton stalk before chopping

Table 1 shows the plant height, stalk/m^2 rate and stalk diameter values (measured in three different parts by taking the collar as the basis). These values serve as indicators for the amount of the stalk which was effective on the chopping mechanization and of the stalk which remained in the field after chopping process. The results in Table 1 demonstrate that the mean height of the post-harvest cotton stalks that remained in the experiment field after chopping was 79.36 cm. Stalk Number/m^2 was

Table 1. Physical characteristics of the pre-harvest cotton.

	Plant Height (cm)	Stalk Density (unit/m^2)	Stalk Diameter		
			A (0-10 cm)	B (10-20 cm)	C (20-30 cm)
Min	65	9	10.5	7.6	6.1
Max	102	13	19.8	15.1	11.5
Average	79.36	10.6	14.12	11.55	9.06
SD	9.64	1.18	2.72	1.89	1.57
VC%	5.29	9.74	8.44	6.19	7.26

Table 2. Piece size frequency distribution in chopping with chained-type stalk chopper.

Classes (cm)	Class Mean (X)	Freq. (f)	f.X	Relative Freq. %
0 - 10.0	6.97	118	822.46	44.37
10.1 - 20.0	13.89	109	1514.01	40.97
20.1 - 30.0	25.63	19	486.97	7.14
30.1 - 40.0	33.76	13	438.88	4.89
40.1 - 50.0	45.0	5	225	1.87
50.1 - 60.0	53.0	2	106	0.76
Total		266	3593.32	100

X_{ort} = 13.38; SD = 9.07; VC% = 32.30.

Table 3. Piece size frequency distribution in chopping with lined-type stalk chopper.

Classes (cm)	Class Mean (X)	Freq. (f)	f.X	Relative Freq. %
0 - 10.0	3.27	268	1680.36	50.18
10.1 - 20.0	14.55	165	2400.75	30.89
20.1 - 30.0	23.71	51	1209.21	9.55
30.1 - 40.0	34.57	35	1209.95	6.55
40.1 - 50.0	43.64	12	523.68	2.26
50.1 - 60.0	52.66	3	157.98	0.57
Total		534	7181.93	100

X_{ort} = 18.32; SD= 12.45; VC%= 21.37.

calculated to determine stalk density; mean stalk density/ m^2 was found to be 10.6unit/m^2. The optimal chopping height for the cotton stalk was the height closest to the soil. However, in the scope of this study, stalk dimensions were measured at three different parts (taking collar as basis). Mean stalk diameter values were found to be 14.12 cm in Part A (0 - 10 cm); 11.55 cm in Part B (20 - 30 cm); and 9.06 cm in Part C (20 - 30 cm). The values (physical characteristics) of the cotton stalk obtained at the end of experiments support the findings of about physical characteristics of soilage corn stalk of Kocabıyık et al. (2009).

Post-chopping physical characteristics

Piece size

Distributions of the piece sizes obtained after the chopping process undertaken by the three choppers are shown in Tables 2, 3 and 4. At the end of the experiments with chained-type stalk chopper, piece size was found to vary between 6.97 and 53.0 cm. However, piece size was mainly within the 1-20 cm range and the mean piece size was 13.38 cm. In the light of this finding, it can be concluded that there is a considerable difference between post-chopping piece sizes. Chopping experiments made with splined-type stalk chopper produced piece sizes varying between 3.27 and 52.66 cm, with a mean piece size of 18.32 cm. The majority of piece was between 1- 20cm (81.07%).

The experiments using the vertical-blade rotating dredge showed that the chopping rate of the stalks was too low. The mean piece size ranged between 7.08 and 74.62 cm. Piece sizes frequently varied between 20 - 50 cm in length (63.12%) and the mean piece size was 28.36 cm. According to experimental principles of stalk choppers, the size of

Table 4. Piece size frequency distribution in chopping with vertical-blade rotating dredge.

Classes (cm)	Class Mean (X)	Freq. (f)	f.X	Relative Freq. %
0 - 10.0	7.08	24	552.24	12.12
10.1 - 20.0	15.40	27	1355.2	13.63
20.1 - 30.0	25.37	42	938.69	21.21
30.1 - 40.0	36.62	47	1061.98	23.73
40.1 - 50.0	47.73	36	811.41	18.18
50.1 - 60.0	57.71	14	807.94	7.08
60.1 - 70.0	74.62	8	516.96	4.04

X_{ort} = 28.36; SD = 17.01; VC%= 39.51.

Table 5. Chopping rate of stalk choppers (unit/m).

Chopper	Min.	Max.	Mean	SD	VC%
Splined-type stalk chopper	8.74	11.25	10.22a	1.22	24.85
Chained-type stalk chopper	3.5	8.92	7.42b	2.34	34.66
Vertical-blade rotating dredge	1.24	5.63	3.95c	1.78	40.77

LSD ($p < 0.05$) = 1.34

the chopped stalk should be 10 - 15 cm and the variation coefficient (VC%) should be 20 -30%. It was found that 89% of the piece sizes produced by the experiments using only the vertical-blade rotating dredge varied between 20 - 40 cm and the variation coefficient was found to be 39.51%. This data falls outside the range of normally acceptable limits. The experiments using the splined-type stalk chopper and chained-type stalk chopper produced results falling within or close to the limits specified. Values obtained at the end of stalk chopping experiments support the findings of Kocabıyık (2003), who experimented on chopping and mixing with soil of sunflower stalks and with the findings of Durdiyev and Dursun (2002), who experimented on chopping of corn stalk. Since it affects cultivation quality, the piece size value obtained from the chopping processes undertaken with splined-type and chained-type stalk choppers is included in the suggested piece size group (Önal and Aykas, 1997; Colwick et al., 1971). Numerical data can be used to make a standard evaluation on the chopping of cotton stalk which were taken from the measurements made after the choppers were driven across the field once.

Chopping rate

Chopping rate -which is another indicator of the capacity of choppers and chopper combinations to chop cotton stalks- is shown in Table 5. The number of the chopped cotton stalks among the cotton stalks within 1 m^2 was taken into consideration while calculating the chopping rate. The highest chopping value was produced by the splined-type stalk chopper at 10.22ea/m^2. The lowest chopping value was recorded as 3.95ea/m^2 in the experiment using the vertical-blade rotating dredge. Chopping rates obtained at the end of stalk chopping experiments support the findings of Kocabıyık (2003), who experimented on chopping and mixing with soil of sunflower stalks and with the findings of Durdiyev and Dursun (2002), who experimented on chopping of corn stalk. The stalk chopping process using only the vertical-blade rotating dredge proved to chop an insufficient proportion of the stalks. Some statistically significant differences were observed between the rates of chopping ($p < 0.05$).

Post-chopping stalk amount

The amounts of stalks remaining on the field surface after the chopping process are shown in Table 6. The greatest quantity of stalk residues (that remained on the field surface after the chopping process) was recorded as 489 number/m^2 in the experiment fields where the splined-type stalk chopper was used. This large quantity of stalk residue is indicative of a successfully chopping process.

The amount and size of the non-uprooted stalks remaining on the field after stalk chopping process

The amount of the non-uprooted and non-chopped stalks that remained on the field surface after chopping process is shown in Table 7. The frequency distributions of the chopped residue for the 3 types of choppers are shown in Table 8, 9 and 10. The splined-type stalk chopper left the smallest quantity (0.8ea/m^2) of un-processed stalks on the field surface after the chopping process, compared

Table 6. The amount of chopped cotton stalks residues remaining on the surface after chopping (Number/m^2).

Chopper	Min.	Max.	Mean
Splined-type stalk chopper	288	594	489a
Chained-type stalk chopper	182	326	274b
Vertical-blade rotating dredge	67	218	173c

LSD ($p < 0.05$) = 92.51

Table 7. Non-uprooted and non-chopped stalks remaining on the field surface after chopping process (ea/m^2).

Chopper	Min.	Max.	Mean	SD
Splined-type stalk chopper	0	2	0.8c	1.0
Chained-type stalk chopper	3	7	4b	1.6
Vertical-blade rotating dredge	6	11	8.0a	2.56

LSD ($p < 0.05$) = 1.74

Table 8. Frequency distribution stalk sizes remaining on the field surface after chopping with splined-type stalk chopper.

Classes (cm)	Class Mean (X)	Freq. (f)	f.X	Relative Freq. %
0 - 3.1	1.5	2	3	2.94
3.1 - 6.0	4.6	10	46	14.71
6.1 - 10.0	7.96	28	222.88	41.17
10.1 - 15.0	12.8	10	128	14.71
15.1 - 20.0	17.07	13	221.91	19.12
20.1 - 25.0	21.33	3	63.99	4.41
25.1 - 30.0	27.5	2	55	2.94

X_{ort} = 10.89; SD = 5.88; VC% = 22.18.

Table 9. Frequency distribution of stalk sizes remaining on the field surface after chopping with chained-type stalk chopper.

Classes (cm)	Class Mean (X)	Freq. (f)	f.X	Relative Freq. %
10.0 - 15.0	13.88	9	124.92	7.37
15.1 - 20.0	17.53	13	227.89	10.66
20.1 - 25.0	22.68	19	430.92	15.57
25.1 - 30.0	29.04	25	726	20.49
31.1 - 35.0	32.86	29	952.94	23.77
35.1 - 40.0	37.07	14	518.98	11.48
40.1 - 45.0	43.77	9	393.93	7.37
45.1 - >	53.0	4	212	3.28

X_{ort}= 23.46; SD = 9.32; VC%= 17.36.

with 8.0 ea/m^2 for the vertical-blade rotating dredge. The stalks that remained on the field surface after chopping experiments with the splined-type chopper mostly varied from 6.1 - 10.0 cm (41.17%). The mean size of the stalks that remained on the field surface was 10.89 cm.

A considerable increase was recorded in the number of the stalks that remained on the field surface after the experiments using the chained-type stalk chopper. Moreover, the size of the stalks remaining varied from 20 - 30 cm. This is a quite high value in terms of stalk

Table 10. Frequency distribution of stalk sizes remaining on the field surface after chopping with vertical-blade rotating dredge.

Classes (cm)	Class Mean (X)	Freq. (f)	f.X	Relative Freq. %
10.0 - 15.0	14.63	12	175.56	6.15
15.1 - 20.0	18.22	11	200.42	5.64
20.1 - 25.0	22.68	19	430.92	9.74
25.1 - 30.0	27.33	17	464.61	8.72
31.1 - 35.0	32.86	29	952.94	14.87
35.1 - 40.0	36.45	43	1567.35	22.05
40.1 - 45.0	41.22	30	1236.6	15.38
45.1 - >	48.8	34	1659.2	17.44

X_{ort} = 37.92; SD = 10.71; VC% = 28.35.

Table 11. Basic Performance Indicators of the Choppers Used in Experiments.

Machine	Working speed (km/h)	Fuel cons. (l/hectare)	network success (da/h)	Work success (da/h)	Field eff. (%)
Splined-type stalk chopper	3.5	6.6	8.8	12.96	0.68
Chained-type stalk chopper	6.1	5.0	10.4	12.744	0.82
Vertical-blade rotating dredge	5.5	7.1	6.6	11	0.60

chopping. The mean height of the stalks that remained on the field surface was found to be 23.4 cm. The values about the amount and size of the non-uprooted stalks remaining on the field after stalk chopping process obtained at the end of stalk chopping experiments support the findings of Kocabıyık (2003), who experimented on chopping and mixing with soil of sunflower stalks. Compared with the two other types of chopper, the experiments using the vertical-blade rotating dredge left more and larger, stalks on the field surface. Mean stalk size was found to be 31.92 cm, while most of the stalks within the 31.1 - 40.0 cm range (36.92%).

Basic performance values of the choppers

Working speed, fuel consumption, net work success, theoretical work success and field efficiency of the choppers used in experiments are shown in Table 11. Among the choppers and chopper combinations used in experiments, the highest working speed was recorded by the chained-type stalk chopper (6.1 km/h). In the experiments in which choppers were used alone (no combination), the vertical-blade rotating dredge produced the highest working speed, of 7.1 km/h. The lowest fuel consumption was recorded as 5.0 l/da by the chained-type stalk chopper in the experiments with single chopper. The highest chopping performance was shown by the splined-type stalk chopper with fuel consumption of 6.6 l/da.

The study produced results which are similar to those produced by other studies conducted on stalk chopping. Choppers and chopper combinations other than the vertical-blade rotating dredge and splined-type stalk chopper were found to produce net work success values higher than the value presented. Basic performance values of the choppers obtained at the end of stalk chopping experiments support the findings of Kocabiyik and kayisoglu (2005).

Conclusion

Thanks to the amount of the cotton produced and the area of cotton production; cotton plays an important role in the agricultural sector of, particularly, Southeastern Anatolia Region and Turkey. Three different types of choppers (namely; splined-type stalk chopper, chained-type stalk chopper and vertical-blade rotating dredge) were used to evaluate the chopping of cotton stalks that remain in the field after harvest. The following results are presented and suggestions offered:

1. The field is ploughed after the cotton was harvest and partially-surfaced stalks are collected by workers. This is hard manual work and it is becoming difficult to find the required workforce.
2. Stalks should be removed from the field or chopped and mixed into the soil in the post-harvest process. Since Turkey lacks large scale facilities to process cotton stalks, the most appropriate method is to chop the stalks and mix them into the soil.
3. Among the 3 different mechanized stalk choppers tested in this study, the splined-type stalk chopper

showed the best chopping performance. The splined-type stalk chopper produced the best results in terms of both piece size and mixing of pieces into the soil. Thus, splined-type stalk choppers can be suggested as an ideal machine to chop cotton stalks.
4. Taking into consideration working speed, work success and fuel consumption of the choppers, as well as the chopping rate of the cotton stalks, splined-type stalk choppers seem to have produced the best results. Increasing the number of drives by the producers so as to increase the chopping efficiency of splined-type and chained-type stalk choppers (which are widely used today to chop the stalks) has a negative effect in terms of the performance of these choppers and the chopping cost/unit area, workforce need and energy inputs increase. Therefore, although it will increase fuel consumption, time and workforce to some extent, the use of a soil processing device together with a stalk chopper is suggested, as it will increase the rate of stalk subsidence following the chopping process.

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