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Effect of Different Vane Combinations on Fertilizer Distribution Uniformity with Various Flow Rates in Spinning Disc Broadcasters

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ABSTRACT

Vanes throwing the particles of fertilizer or granular material onto a field are one of the most important machine parts influencing the fertilizer distribution pattern in spinning disc broadcasters. Manufacturers prefer mostly straight-shaped vanes in spinning disc broadcasters, probably because their production is easy. In previous studies, therefore, many researchers studied the spinning disc broadcaster with the straight-shaped vanes only. In this study, the effect of the combinations of the straight-shaped vane with different shaped vanes on the fertilizer distribution uniformity in single-spinning disc broadcaster was investigated with various flow rates using triple superphosphate. The combinations used in the study were the straight-shaped vane in combination with forward-curved-5, forward-curved-10, back-curved-5, and back-curved-10 vane, and “no combination” consisted of the straight-shaped vane only. The circular orifices of 30, 40 and 50 mm diameters were used at the bottom of hopper to obtain the different flow rates of the fertilizer. The results of the study showed that the combination of the different shaped vanes on the spinning disc had a significant effect on fertilizer distribution uniformity. “No combination” used commonly in practice did not give the best fertilizer distribution uniformity. The best fertilizer distribution uniformity was obtained from the combination of the straight-shaped vane with forward-curved-5 vane shape for all the flow rates. The CV values obtained from this combination were 10.31%, 15.49%, and 19.92% for the orifices with diameters of 30, 40 and 50 mm, respectively.

Keywords: Vane shape; Distribution uniformity; Fertilizer broadcaster; Distribution pattern; Flow rate

Diskli Dağıtma Makinalarında Farklı Kanat Kombinasyonlarının Değişik Debilerde Gübre Dağılım Düzgünlüğüne Etkisi

ESER BİLGİSİ

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ÖZET

Taneli materyali ya da kimyasal gübreyi tarlaya fırlatan kanatlar, diskli gübre dağıtma makinalarında gübre dağılım desenini etkileyen en önemli makina parçalarından biridir. İmalatçılar muhtemelen üretimleri kolay olduğu için,

diskli gübre dağıtma makinalarında çoğunlukla düz şekilli kanatları tercih etmektedirler. Bundan dolayı, önceki çalışmalarda, çoğu araştırmacı sadece düz şekilli kanatlara sahip diskli gübre dağıtma makinalarını incelemişlerdir. Bu çalışmada, farklı şekilli kanatlar ile düz şekilli kanat kombinasyonlarının triple süper fosfat gübresi kullanarak, değişik debilerde gübre dağılım düzgünlüğü üzerine etkisi incelenmiştir. Araştırmada ileri bükük-5, ileri bükük-10, geri bükük-5, geri bükük-10 kanatlar ile düz şekilli kanadın oluşturduğu kombinasyonlar ve sadece kombinasyon oluşturmayan düz kanatlar kullanılmıştır. Farklı gübre debileri elde etmek amacıyla depo tabanında 30, 40 ve 50 mm çaplarında daire şeklindeki çıkış delikleri kullanılmıştır. Araştırma sonuçları, dağıtıcı disk üzerindeki farklı şekilli kanat kombinasyonlarının gübre dağılım düzgünlüğü üzerinde önemli bir etkisinin olduğunu göstermiştir. Uygulamada yaygın olarak kullanılan ve sadece düz kanattan oluşan kombinasyonsuz seçeneği en iyi gübre dağılım düzgünlüğünü sağlamamıştır. Bütün gübre debilerinde, en iyi gübre dağılım düzgünlüğü ileri bükük-5 kanat ile düz kanadın oluşturduğu kombinasyondan elde edilmiştir. Bu kombinasyondan elde edilen CV değerleri, 30, 40 ve 50 mm çıkış deliği çapları için sırasıyla, %10.31, %15.49 ve %19.92 olarak belirlenmiştir.

Anahtar sözcükler: Kanat şekli; Dağılım düzgünlüğü; Gübre dağıtma makinası; Dağılım deseni; Debi

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1. Introduction

Spinning disc broadcasters have widely been used in Turkey due to their simple construction, economical price and effectiveness. For instance, the number of spinning disc broadcasters in use has reached 366,781 in the year of 2010 in Turkey, increasing 23.19% for the last decade (TÜİK 2011).

One of the most important parameters which affect the distribution uniformity in spinning disc broadcasters is the flow rate of fertilizer on spinning disc. The previous studies showed that the uniformity of fertilizer distribution decreased as the flow rate increased (Çarman 1992; Parish 2002; Yıldırım & Kara 2003; Yıldırım 2006a & b; Yıldırım & Öztürk 2007). Çarman (1991), Olierslagers et al (1996), and Yıldırım (2006a & b) reported that the fertilizer distribution pattern was better when the revolution speeds of spinning disc for higher flow rates of the fertilizer was increased with straight vanes with no combinations. Yıldırım & Kara (2003) determined that the fertilizer distribution evenness became better when the vane height was increased for high flow rates.

The design properties of vane on spinning disc have important effects on fertilizer distribution patterns in spinning disc broadcasters. The vane properties such as height, shape, position on disc, and profile type have the important effects on the distribution uniformity of the fertilizer in spinning disc broadcasters (Özmerzi 1974; Erol & Özmerzi

1977; Önal & Tozan 1984; Yetkin & Çarman 1988; Yıldırım & Kara 2003; Özbek et al 2006; Yıldırım 2008a). The vanes used on spinning discs can be straight, curved or composite-shaped (Srivastava et al 1993). However, the vanes except straight-shaped ones are not mostly produced by manufacturers. The reason for this may be the ease of the straight-shaped vanes. Also, manufacturers do not primarily use the combination of the different shaped vanes on spinning disc. For this reason, in previous studies, many researchers studied the spinning disc broadcaster with the straight-shaped vanes only.

A few researchers studied on the different shapes of vane. Yıldırım (2008a) investigated the effect of the different vane shapes on the fertilizer distribution pattern using triple superphosphate and calcium ammonium nitrate with the single flow rate in single spinning disc broadcasters. The author used the forward-curved-5, forward-curved-10, back-curved-5, back-curved-10, and straight vane on a flat disc in a radial position. The author determined that the best and worst distribution patterns for both triple superphosphate and calcium ammonium nitrate were obtained from the forward-curved-5 and forward-curved-10 vane shape, respectively. Parish (2003a) investigated five commercial walk-behind spinning disc broadcasters to evaluate the ability of pattern correction systems. Three of these broadcasters had the straight vanes only with flat disc, one of these consisted of the straight vane with concave-shaped spinning disc,

and the other had a vane combination with two straight and two curved vanes on a flat spinning disc. All of these broadcasters had four vanes on their own discs. According to the results of the study, the best distribution pattern was obtained from broadcaster with vane combination with two straight and two curved vanes. However, these machines were different from each other in terms of the spinning disc height (27.9 to 36.2 cm), spinning disc diameter (22.9 to 30.5 cm), spinning disc shape (concave, flat), rotational speeds of disc (336 to 412 min^{-1} for 4.8 km h^{-1}) metering port shapes and configurations, and mechanisms of discharging of fertilizer through ports. Consequently, it is not clear highly unlikely that the best distribution pattern is only obtained due to the vane combination with two straight and two curved vanes. Hence, the combination of the different shaped vanes should be investigated on the same fertilizer broadcaster to focus on the effect of vane combinations on the fertilizer distribution pattern. Furthermore, the effect of the different vane combinations under the influence of the different flow rates of fertilizer on the uniformity of the fertilizer distribution was not evaluated in previous studies.

The objective of this study was to determine the effect of the different vane combinations on the fertilizer distribution pattern and the vane combination giving the best distribution uniformity for the various flow rates of the fertilizer.

2. Materials and Methods

Five different vane combinations, including “no combination”, were used on the same spinning disc in the study. The vane shapes used in the study were straight, forward-curved, and back-curved. Each of the forward-curved and back-curved vanes was consisted of two different types as shown in Figure 1. “No combination” was consisted of the straight vanes only. The six vanes were employed for each combination, including “no combination” on the same spinning disc. The shapes, dimensions, positions, and top view of combination of the vanes used in the study are

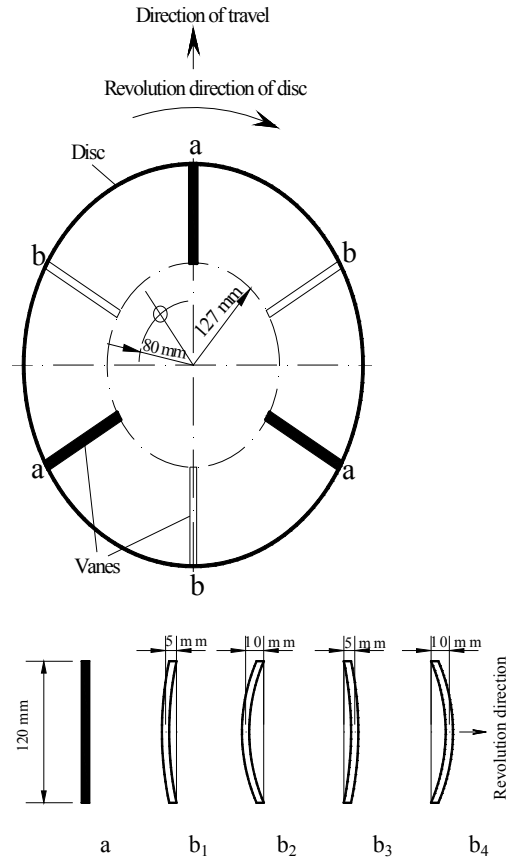


Figure 1-The top view of the vanes and disc used in the study (a: Straight (S), b₁: Forward-curved-5 (FC-5), b₂: Forward-curved-10 (FC-10), b₃: Back-curved-5 (BC-5), b₄: Back-curved-10 (BC-10))

Şekil 1-Çalışmada kullanılan disk ve kanatların üstten görünüşü (a: Düz (S), b₁: İleri bükük-5 (FC-5), b₂: İleri bükük-10 (FC-10), b₃: Geri bükük-5 (BC-5), b₄: Geri bükük-10 (BC-10))

shown in Figure 1. All vanes made of sheet metal had the height of 65 mm and the thickness of 2 mm, and they were mounted in radial position on a flat spinning disc with 500 mm diameter. Three of the six vanes in each combination were the straight-shaped, and the other three were different shaped in accordance with combination used (Figure 1). The distance between the center of

spinning disc and the inner end of vanes on the disc was 127 mm (Figure 1). As it is seen in the Figure 1, the vane combinations used in the study were arranged as $a \times b_1$, $a \times b_2$, $a \times b_3$, and $a \times b_4$.

Triple superphosphate was used in the study. The values of sieve analysis, bulk density, repose angle, and moisture content of the fertilizer are shown in Table 1. The circular orifices with diameters of 30, 40 and 50 mm at the bottom of the conical fertilizer hopper were used for obtaining various flow rates. The flow rates obtained from these orifices are 9.32, 24.58 and 48.09 kg min⁻¹, respectively. The distance between the centers of all orifices used in the study and the center of the spinning disc, known as feed radius, was 80 mm. The feed radius did not change as the orifice diameter was increased because the orifices were circular shaped.

Pattern tests for all vane combinations including “no combination” with the various flow rate of the fertilizer were conducted and the coefficients of variation (CV) based on the side-by-side circuitous mode of operation were calculated according to ASAE S341.2 (ASAE Standards, 1998). Prior to the replicated tests, the optimized patterns that minimized skewing from side to side for each orifice diameter and vane combination were obtained by shifting the angular position of the dropping of the fertilizer on disc, and then the optimized patterns were replicated three times.

The spinning disc was level and the height from the top of collection trays was 650 mm during the tests. The single-spinning disc broadcaster operated with a power take-off (PTO) speed of 540 min⁻¹ was moved over the collection trays along the same centerline at a speed of 5.8 km h⁻¹. One tray was omitted on each side of the center to allow the tractor wheels to pass through the collection trays during tests. The fertilizer rates at the locations without tray were interpolated from the adjacent collection trays (Parish 2003b). The arrangement on the testing area, dimensions and shape of collection trays were the same with those of Yıldırım (2008 a&b).

Table 1-Physical properties of triple superphosphate

Çizelge 1-Triple süperfosfatın fiziksel özellikleri

Sieve Fraction	% retained on sieve
<1.6 mm	0.85
1.6-2.00 mm	3.59
2.00-2.80 mm	55.05
2.80-3.35 mm	24.85
3.35-4 mm	14.27
>4 mm	1.39
Mass median diameter (mm)	2.74
Bulk density (kg m ⁻³)	1157
Moisture content (%)	2.51
Repose angle (°)	31.50

3. Results and Discussion

Totally 45 optimized distribution patterns were obtained from five vane combinations at three flow rates for triple superphosphate. The values of CV, skewing, and minimum and maximum belonging to the overlapped patterns are shown in Table 2. Typical acceptable levels for these parameters are CV \leq 20%, minimum \geq 80% of the mean rate, and maximum \leq 120% of the mean rate (Parish 2001). In addition to these values, the working width and the range of working width for the distribution patterns with \leq 20CV% are shown in the same table. All data were analyzed by one-way analysis of variance (ANOVA) for each orifice diameter, separately. According to the results of the ANOVA, vane combination had a significant effect ($P<0.05$) on the CV, skewing, and minimum and maximum values for each orifice diameters (Table 2).

According to the data in Table 2, the best distribution uniformity was obtained from the combination of S and FC-5 for all the orifice diameters. The minimum CV values obtained from this combination were 10.31%, 15.49%, and 19.92% for the orifice diameter of 30, 40 and 50 mm, respectively. “No combination” consisting of straight-shaped vanes only, mostly common used in practice, did not give the best

Table 2-Characteristics of overlapped patterns obtained from the different combinations of vane for each orifice diameters^[a]*Çizelge 2-Her bir çıkış deliği çapı için farklı kanat kombinasyonlarından elde edilen örtmeli desenlerin özellikleri*

Orifice diameter (mm) / Flow rate (kg min ⁻¹)	Vane combination ^[b]	We ^[c] (m)	Range of working width ^[d] (m)	CV ^[e] (%)	Skewing ^[f] (%Left/%Right)	Min. ^[g] (%)	Max. ^[g] (%)
30 / 9.32	No combination	13.5	12.00 ... 14.00	17.68 b	48/52 ab	76 a	132 ab
	S and FC-5	9	08.50 ... 11.00	10.31 d	47/53 b	77 a	116 d
	S and FC-10	10	----	21.53 a	49/51 a	64 b	139 a
	S and BC-5	9	08.50 ... 10.50	14.58 c	45/55 c	75 a	127 bc
	S and BC-10	9	08.50 ... 10.00	14.44 c	46/54 c	72 a	124 c
	LSD _{0.05}				0.8436	1.485	4.554
40 / 24.58	No combination	11	----	20.60 b	43/57 c	71 a	145 b
	S and FC-5	11	08.50 ... 13.00	15.49 d	45/55 b	77 a	131 c
	S and FC-10	12	----	26.42 a	43/57 c	69 a	168 a
	S and BC-5	14	13.00 ... 15.00	18.24 c	48/52 a	70 a	137 bc
	S and BC-10	12	11.50 ... 13.00	18.40 c	46/54 b	61 b	129 c
	LSD _{0.05}				1.386	01.328	7.617
50 / 48.09	No combination	15	----	26.94 b	42/58 d	66 b	164 a
	S and FC-5	13	13.00 ... 14.00	19.92 d	45/55 a	63 bc	140 d
	S and FC-10	8.5	----	31.10 a	40/60 e	58 c	164 a
	S and BC-5	14	----	21.51 c	44/56 b	64 bc	146 c
	S and BC-10	13	----	22.14 c	43/57 c	73 a	153 b
	LSD _{0.05}				1.142	0.9401	5.830

[a]: Each data point shown is the mean of three replications.

[b]: No combination: the Straight vane only, S: Straight vane, FC: Forward-curved vane, BC: Back-curved vane.

[c]: The effective working width at the minimum CV in overlapped pattern.

[d]: The minimum and maximum working widths at the CV value lower than 20% in overlapped pattern.

[e]: The CV values at width We.

[f]: Skewing in the overlapped pattern is expressed as the percentage of material on the left side of the pattern centerline compared with the percentage of material on the right side of the pattern centerline.

[g]: Minimum and maximum points in the overlapped pattern are expressed as a percentage of the mean rate.

distribution pattern. Moreover, this combination had the second worst distribution uniformity for all orifice diameters. The minimum CV values belonging to “no combination” were 17.68%, 20.60%, and 26.94% for the orifice diameter of 30, 40 and 50 mm, respectively. “No combination” gave the acceptable CV value (<20%) for only the orifice diameter of 30 mm.

The values of CV increased with increasing diameters of orifice for all of the vane combinations. This finding agrees with that of Yıldırım (2006a & b) and Yıldırım & Kara (2003), who reported that the CV values also

increased as increased the orifice diameter. The values of CV obtained from orifice diameter of 30, 40 and 50 mm ranged from 21.53% to 14.44%, from 26.42% to 15.49%, and from 31.10% to 21.51%, respectively. Only the combination of S and FC-10 for the orifice diameter of 30 mm exceeded the acceptable value ($\leq 20\%$) of CV, and this combination gave the worst distribution uniformity for all orifice diameters. For diameter orifice of 50 mm in which the highest flow rate was obtained, only the combination of S and FC-5 gave the acceptable value of CV ($\leq 20\%$). Therefore, this vane

combination can be used to obtain acceptable values of CV for the high flow rate of fertilizer, and so the high application rate of fertilizer on field. The “no combination”, used in practice, gave the acceptable values of CV for only the orifice diameter of 30 mm. Previous studies showed that the fertilizer distribution uniformity became worse as the amount of fertilizer flowing onto spinning disc was increased (Yildirim & Kara 2003; Yildirim 2006a & b).

According to Table 2, the values of skewing were significantly different from 50%Left/50%Right ($P<0.05$) at the 95% level of significance for the orifice diameters of 30, 40 and 50 mm, respectively. Skewing in the overlapped pattern is expressed as the percentage of material on the left side of the pattern centerline compared with the percentage of material on the right side of the pattern centerline. Önal (1995) also reported that the difference between amount of fertilizer on the left side of the pattern centerline and amount of fertilizer on the right side of the pattern centerline (skewing) should be $\leq 4\%$. The best skewing values obtained from overlapped patterns were S and FC-10 (49%Left/51%Right), S and BC-5 (48%Left/52%Right), and S and FC-5

(45%Left/55%Right), for the orifice diameters of 30, 40 and 50 mm, respectively. The most skewing overlapped patterns in Table 2 were S and BC-5 (45%Left/55%Right), “no combination” which was the same with S and FC-10 (43%Left/57%Right), and S and FC-10 (40%Left/60%Right) vane combinations for the orifice diameters of 30, 40 and 50 mm, respectively. Figures 2, 3 & 4 show the optimized distribution patterns obtained from all vane combinations for each orifice diameters of 30, 40 and 50 mm, separately. As is seen in Figures, the optimized distribution patterns had trend in skewing toward the left as the orifice diameter (therefore the flow rate) was increased for all the vane combinations. The reason for this is that the fertilizer leave disc late because of increasing of fertilizer amount on disc with increasing of orifice diameter. This result is similar to the patterns in study of Yildirim & Kara (2003) and Yildirim (2006a). The high skewing is an important problem to obtain the acceptable values of CV.

There were significant differences in minimum values expressed as percentages of the mean rates in the overlapped patterns. The combination of S and FC-5 vane had the best

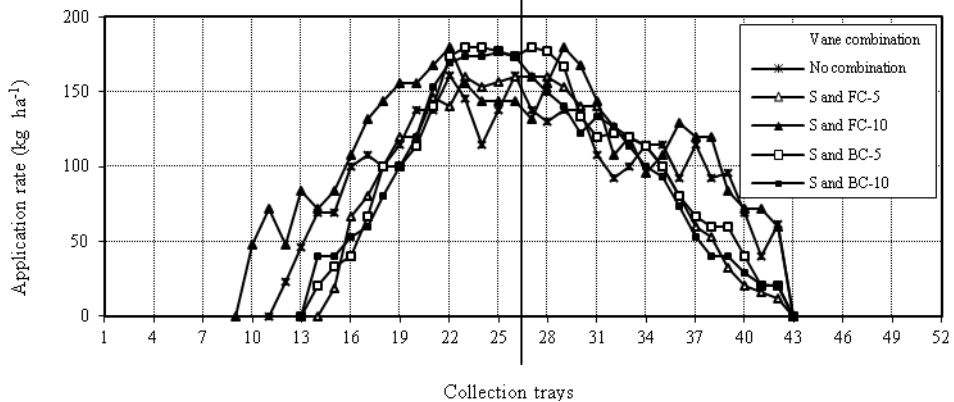


Figure 2-The optimized distribution patterns obtained from the five different combinations of vanes for the orifice diameter of 30 mm. The center of the disc passed midway between the centers of collection trays 26 and 27. Each line is the mean of three replications

Şekil 2. Farklı kanat kombinasyonlarından 30 mm çapındaki çıkış deliği için elde edilen optimum dağılım desenleri. Disk merkezi 26 ile 27 numaralı toplama kutularının arasından geçmektedir. Grafik çizgilerinin her biri üç tekrarin ortalamasıdır

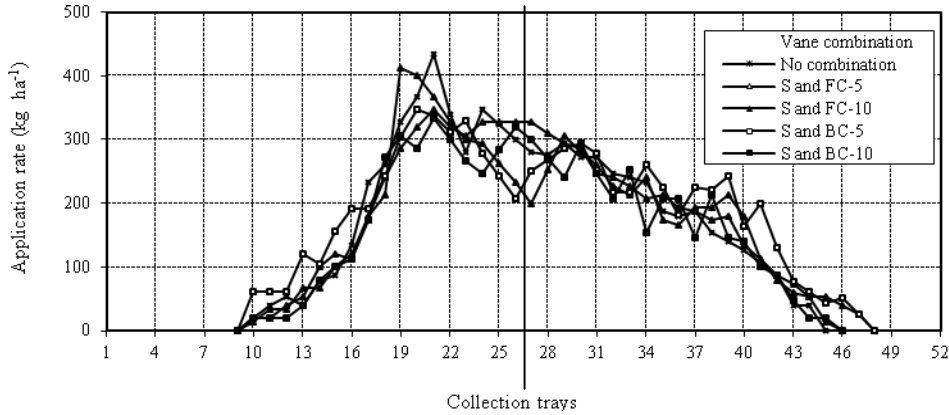


Figure 3-The optimized distribution patterns obtained from the five different combinations of vanes for the orifice diameter of 40 mm. The center of the disc passed midway between the centers of collection trays 26 and 27. Each line is the mean of three replications

Şekil 3-Farklı kanat kombinasyonlarından 40 mm çapındaki çıkış deliği için elde edilen optimum dağılım desenleri. Disk merkezi 26 ile 27 numaralı toplama kutularının arasından geçmektedir. Grafik çizgilerinin her biri üç tekrerrün ortalamasıdır

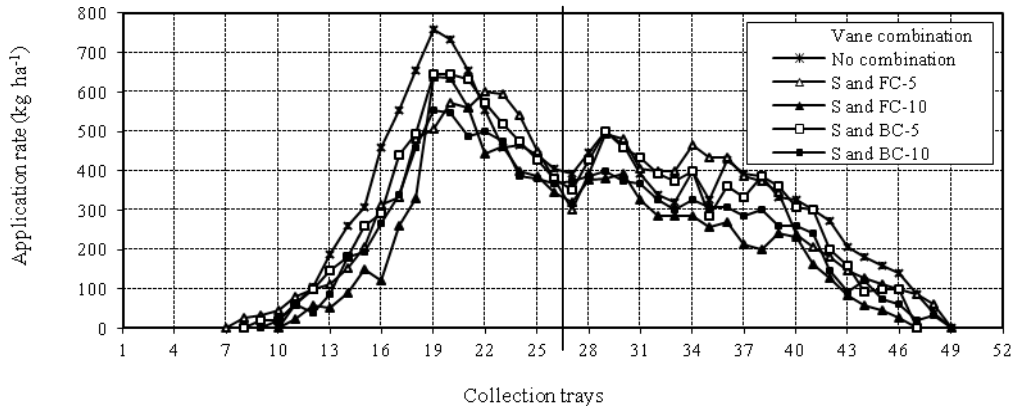


Figure 4-The optimized distribution patterns obtained from the five different combinations of vanes for the orifice diameter of 50 mm. The center of the disc passed midway between the centers of collection trays 26 and 27. Each line is the mean of three replications

Şekil 4-Farklı kanat kombinasyonlarından 50 mm çapındaki çıkış deliği için elde edilen optimum dağılım desenleri. Disk merkezi 26 ile 27 numaralı toplama kutularının arasından geçmektedir. Grafik çizgilerinin her biri üç tekrerrün ortalamasıdır

results (*i.e.* the minimum values were closest to 100%) for the orifice diameter of 30 and 40 mm. The best minimum value belonging to the orifice diameter of 50 mm was obtained from the S and BC-10 vane combination. The S and FC-10 for

the orifice diameter of 30 and 50 mm, S and BC-10 for the orifice diameter of 40 mm had the worst results (*i.e.* the minimum values were the lowest).

The vane combinations including “no combination” also showed significant differences in maximum points in the overlapped patterns. These values also expressed as percentages of the mean rates. The best results in maximum values (*i.e.*, the closest values to 100%) obtained from S and FC-5 for the orifice diameter of 30 and 50 mm. The S and BC-10 vane combination had the best value along with S and FC-5 statistically for the orifice diameter of 40 mm. The S and FC-10 vane combination along with “No combination” gave the worst results (*i.e.*, the highest maximum values) in maximum values for all orifices except the orifice diameter of 40 mm. The worst maximum value for this orifice was obtained only from the S and FC-10 vane combination.

With one type of vanes such as straight, forward curved or backward curved and a single metering port, the pattern will tend to have a peak; however, the peaks will be at different lateral locations for each type of vane. Combining two types will tend to give two smaller peaks rather than on major peak, and thus will make the overall pattern smoother. This effect can be seen in the graphs in Figures 2, 3 & 4.

The ranges of working width calculated as the minimum and maximum working widths at the CV value lower than only 20% in overlapped pattern are shown in Table 2. The more the ranges of working width is wide, the greater tolerance the fertilizer broadcaster will have to external factors such as wind and variations in working width arising from operator errors. The combination consisting of S and FC-5 vane had the widest ranges for all orifice diameters. These ranges were 2.5, 4.5 and 1 m for the orifice diameter of 30, 40 and 50 mm, respectively.

4. Conclusions

Results from this research indicated that the vane combination had an important effect on the distribution uniformity of triple superphosphate for the various flow rates. The fertilizer distribution uniformity became worse as the flow rate of the fertilizer increased for all vane combinations including “no combination”. “No

combination” had worst distribution uniformity after the combination of straight and forward-curved-10 vane. Only the straight and forward-curved-5 vane combination giving the best distribution uniformity for all flow rates of fertilizer provided the acceptable value of CV for the highest flow rate; hence it can be suitable with the spinning disc broadcasters for the high application rates of fertilizer.

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