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Ecological production of dryland hairy vetch by mechanical control

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Abstract – Winter hairy vetch, *Vicia villosa* Roth, gives high grain and hay yields. Mechanical control of weeds is an ecological alternative to the use of herbicides. Among the various mechanical methods, interrow weeding is cheap and practical. Nonetheless, wider row spacing than common practice is needed to ease the operation. We optimized row spacing and seed rates for high grain yield and to ease interrow cultivation. We used two row spacings of 45 and 60 cm as main plots and five seeding rates of 100, 200, 300, 400 and 500 seed per square meter as subplots. Experiments were conducted in rotation with winter wheat in 2001, 2002 and 2003. The results showed that narrow spacing and high seed rates increased the grain yields of winter hairy vetch. In contrast, wide row spacing reduced the grain yield by 56%. More plants per square meter were obtained with 60-cm row spacing and high seed rates. Row spacing of 60 cm increased the branch number per plant in the dry year and decreased it in the wet year.

winter hairy vetch / row spacing / seed rate / grain yield / yield components / path analysis

1. INTRODUCTION

Grains of vetch (*Vicia* spp.) have been used for animal feeding by mixing broken seeds with fodder or cereal seeds in Turkey and in many other Middle-Eastern and Mediterranean countries. It is also very important as a fodder crop cultivated for livestock-oriented farms in coastal areas of Turkey. According to SIS (2003), vetches are commonly cultivated in forage crops, about 600 thousand hectares; therefore, seed production is one of the crucial problems for the expansion of forage crop production in Turkey.

In crop production, maximum grain yield can be obtained by reducing intercrop and crop-weed competitions to a minimum level. This is generally accomplished by optimizing seed rates and row spacing. It is reported that 17.5-cm row spacing with a seeding rate of 120 kg per ha (about 325 seeds per square meter) produces more grain than other treatments when average growing season precipitation is less than 300 mm and if the growing season precipitation exceeds this amount, the seeding rate should be increased to 150 kg per ha, approximately 400 seeds per square meter, in Central Anatolian conditions (Munzur et al., 1995). In southwestern Australia, target densities of 40 plants per square meter on average, 33 plants per square meter for late cultivars and 60 plants per square meter for high-yielding areas (>1.5 t per ha), were found for an early cultivar of *Vicia sativa* (Seymour et al., 2002).

Winter vetch is superior to the spring one in terms of grain and hay yields. However, weed control is the main problem in winter legume production. A study conducted in Central Anatolia shows that effective weed control in winter vetch provides 100% yield increase in grain yield as an average of four years

and caused 25–51% increases in subsequent wheat yields, as well (Avci et al., 1996). Weeds must be removed twice in spring and means of mechanical weed control are the only remedy in large-scale production, due to lack of effective herbicides, cost and unavailability of labor for effective weed control (Meyveci et al., 1998). Interrow weeding is one of the cheapest and most rapid methods for weed control. However, wider row spacing is required to facilitate tractor and cultivator performance and avoid damage to the crop during cultivation. Therefore, the objectives of this research were to find the optimum row spacing to allow effective interrow cultivation and seed rates to provide high grain yield.

2. MATERIALS AND METHODS

Winter vetch cv. Munzur-98 developed by the Central Research Institute for Field Crops (CRIFC) was used as the plant material in this study. It has semi-prostrate habitus with a rectangular, hollow and hairy stem and 60–120 cm plant height. Its flowers are violet, its pods have 3 to 5 pale black round seeds and the seed weight is 30–50 mg.

The trials were conducted at the Haymana Research Station of CRIFC during the growing periods of 2001, 2002 and 2003. The site has a typical dry continental climate and is located at an altitude of 1055 m. The soil of the site is poor in organic matter (1–2%) and high in clay content and CaCO₃. The long-term average growing period precipitation of the area is 350 mm. Total precipitations received were 233, 433 and 330 mm for the cropping seasons of 2001, 2002 and 2003, respectively. In terms of monthly average temperatures, 2001 was warmer throughout the growing season, and 2002 was similar to 2003

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Figure 1. Path coefficient diagram showing the interrelations among yield and yield components of dryland hairy vetch cultivar (Munzur 98) grown under different spacing and seed rates. (1) Plant number per square meter (Plm2), (2) Branch number per plant (Brpl), (3) Pod number per branch (Podbr), (4) Kernel number per pod (Kpod), (5) Biomass per square meter (Bm), (6) Harvest index% (HI), (7) Thousand kernel weight (KW), (8) Grain yield (GY). P_{ij} denotes the related path coefficients.

but it was colder in winter than the long-term averages of the experimental site.

The trials were conducted in a field sown with winter wheat in the previous year. The seedbed was prepared by offset disks two months after wheat harvest. The trials were planted in the last week of September or in the first week of October and harvested in the first week of July. The sowing was done by cereal drill using 40 kg per ha N and 40 kg per ha P_2O_5 fertilizers. Weeds were controlled by interrow weeding in April and in May. The experimental design was a split plot in Randomized Complete Blocks with 3 replications. The main plots were row spacings of 45 and 60 cm and subplots were seed rates of 100, 200, 300, 400 and 500 seeds per square meter. Agronomic measurements were based on 10 plants randomly selected from each plot. The harvest index and plant number per square meter were calculated by using yield data for grain. The yield model was adopted according to the significance of single degree of orthogonal tests of variables. Economic seed rates for different row spacings were found according to Doll and Orazem (1984).

Path coefficient analysis was performed to obtain further information on the relationship among yield components and their effects on grain yield. The analysis partitions the correlation coefficients (r_{ij}) into direct and indirect effects (Dewey and Lu, 1959). It has been used to identify the important yield components in various crops such as soybean (Rosalind, et al., 2001). A cause-effect diagram was constructed partly based on the ontology of the vetch plant (Fig. 1) and the following four sets of equations were grouped to find the path coefficients, P_{ij} .

$$r_{18} = P_{18} + r_{12} P_{28} + r_{13} P_{38} + r_{14} P_{48} + r_{17} P_{78}$$

$$r_{28} = P_{28} + r_{12} P_{18} + r_{23} P_{38} + r_{24} P_{48} + r_{27} P_{78}$$

$$r_{38} = P_{38} + r_{13} P_{18} + r_{23} P_{28} + r_{34} P_{48} + r_{37} P_{78}$$

$$r_{48} = P_{48} + r_{43} P_{38} + r_{42} P_{28} + r_{41} P_{18} + r_{47} P_{78}$$

$$r_{78} = P_{78} + r_{47} P_{48} + r_{37} P_{38} + r_{27} P_{28} + r_{17} P_{18}$$

$$r_{67} = P_{67} + r_{64} P_{47} + r_{63} P_{37} + r_{62} P_{27} + r_{61} P_{17}$$

$$r_{47} = P_{47} + r_{48} P_{37} + r_{42} P_{27} + r_{41} P_{17} + r_{46} P_{67}$$

$$r_{37} = P_{37} + r_{43} P_{47} + r_{32} P_{27} + r_{31} P_{17} + r_{36} P_{67}$$

$$r_{27} = P_{27} + r_{24} P_{47} + r_{23} P_{37} + r_{21} P_{18} + r_{26} P_{67}$$

$$r_{17} = P_{17} + r_{12} P_{27} + r_{13} P_{37} + r_{14} P_{47} + r_{16} P_{67}$$

$$r_{36} = P_{36} + r_{34} P_{46} + r_{35} P_{56}$$

$$r_{46} = P_{46} + r_{43} P_{36} + r_{45} P_{56}$$

$$r_{56} = P_{56} + r_{35} P_{36} + r_{54} P_{46}$$

$$r_{15} = P_{15} + r_{12} P_{25}$$

$$r_{25} = P_{25} + r_{21} P_{15}$$

3. RESULTS AND DISCUSSION

3.1. Grain yields

Grain yields over all treatments and years averaged 798 kg per ha (Tab. I). The yield differences between the years were statistically significant, with an $LSD_{0.05} = 100.0$ kg per ha. The average yield in the dry year of 2001 was 740 kg per ha, 1042 kg per ha in the normal year of 2002 and 614 kg per ha in the wet but cold winter season of 2003, which adversely affected the vetch yield. The highest grain yield (1220 kg per ha) was obtained in 2002 with 60-cm spacing and a 200 seed rate per square meter. Row spacing and the row spacing $\times$ year interaction were significant for grain yields only in 2002 ($LSD_{0.05} = 50.8$ kg per ha) and in combined analysis ($LSD_{0.05} = 83.2$ kg per ha), respectively. Seed rates significantly affected grain yields in 2002 ($LSD_{0.05} = 98.9$ kg per ha) and in combined analysis ($LSD_{0.05} = 90.4$ kg per ha). The seeding rate $\times$ row spacing interaction was significant in all years and in combined analysis, except for 2003. The seeding rate $\times$ year and row spacing $\times$ seeding rate $\times$ year interactions were insignificant both in individual and combined analysis (Tab. II). The row spacing $\times$ year interaction mainly resulted from the changing response of vetch yield to 60-cm spacing. As a result, a remarkable grain yield drop was observed with 60-cm row spacing as compared with the other years. Therefore, wider row spacing should not be recommended for areas where the temperature drops to below zero during the winter season. Grain yields were lower

Table I. Mean grain yields of cv. Munzur 98 grown under various row spacings and seed rates (kg/ha).

Row spacing (cm)	Seeds rates (seeds per square meter)					
	100	200	300	400	500	Mean
45	702	954	879	829	810	835
60	825	806	800	721	655	761
Mean	763	880	840	775	733	798

Table II. F probabilities of treatments in the analysis of variance of single years and combined years in terms of grain yields of cv. Munzur 98.

Sources of variation	Years and combination of years			
	2001	2002	2003	Combined
Years	—	—	—	0.000
Block	0.205	0.061	0.618	0.427
Row spacing	0.406	0.019	0.106	0.075
Row spacing × year	—	—	—	0.014
Seeding rate	0.376	0.000	0.678	0.012
Seeding rate × row spacing	0.016	0.001	0.773	0.020
Row spacing × year	—	—	—	0.482
Row spacing × year × seeding rate	—	—	—	0.276

in 60-cm spacing for all seed rates than in 45-cm, except for 100 seeds per square meter (Tab. I).

Average yields of the seeding rate × row spacing interaction were used in the analysis to find the maximum and economic rates because the seeding rate × row spacing × year interaction was statistically insignificant in combined analysis. For the validity of the results, average yields over years were used in the analysis rather than individual years and they were also representative of three different years for Central Anatolia (CA). Therefore, linear responses of row spacing × year, linear responses of row spacing × linear response of seed rate × year and linear response of row spacing × cubic response of seed rate interactions were not taken into consideration in the analysis, although they were statistically significant at $P < 0.05$.

Single degree of freedom trend analysis indicated that only the quadratic component of seeding rate and linear × linear interaction of row spacing and seeding rate and row spacing × year interactions were significant at $P < 0.05$ in combined analysis. In 2002, all components except for linear response of row spacing and linear response of row spacing × cubic response of seed rate were significant in 2003 and 2001, respectively (Tab. III). Based on trend analysis, a model was adopted to predict the grain yields including independent variables of linear response of spacing row (S), linear response of seed rate (R), quadratic response of seed rate (R^2) and linear response of seed rate × linear response of spacing row (S_L) components, and high order cubic response of seed rate (R_C) and linear response of spacing row (S_L) × cubic response of seed rate (R_C) components, which had relatively high probability values.

We found the following equation. $Y = -153.0 + 3.236 S + 11.803 R - 0.0345 R^2 - 0.03353 R S + 2.85288 \times 10^{-8} S R^3 + 3.31883 \times 10^{-5} R^3$ ($r^2 = 0.97$), where Y = grain yield, kg per ha. The yield model explains the 97% of variation.

Farmers generally use cereal drills to plant vetch in Central Anatolia. They have variable row spacing options ranging from 14 cm to 20 cm. To create wider spacing between rows, one or two alternate seed holes are closed when planting. Hence, different row spacings can be obtained in farmers' conditions. For any row spacing suitable for tractor tires and cultivator tines, the optimum seed rate can be determined for various row spacing scenarios. The optimal physical and economic seed rates were determined on the third-degree polynomial equation

Table III. F probabilities of seeding rate and row spacing of single degree of freedom orthogonal tests of grain yields of cv. Munzur 98.

Components*	Years and combination of years				
	2001	2002	2003	Combined analysis	Year interactions
Seed rates					
R_L	0.658	0.049	0.391	0.103	0.408
R_Q	0.180	0.000	0.439	0.006	0.123
R_C	0.148	0.077	0.503	0.080	0.882
R_{Qr}	0.829	0.029	0.506	0.749	0.088
Row spacing (S_L)	0.312	0.000	0.012	0.075	0.000
Row spacing × seed rates					
$S_L \times R_L$	0.928	0.000	0.281	0.013	0.044
$S_L \times R_{Qd}$	0.914	0.012	0.607	0.146	0.255
$S_L \times R_C$	0.001	0.799	0.644	0.081	0.059
$S_L \times R_{Qr}$	0.941	0.043	0.830	0.334	0.351

* L: Linear, Q: Quadratic, C: Cubic, Qr: Quartic responses.

Figure 2. Maximum and economic seed rates for different row spacings and respective grain yields of cv. Munzur 98.

curve after replacing row spacing with the desirable values in the original model. They are depicted with the respective grain yields in Figure 2.

The data indicate that narrow spacing and high seeding rates increased the grain yields. Spacing suitable for field practice is between 40 and 50 cm, so the economic seed rates for this should be between 210 seeds (77 kg per ha) and 197 seeds (73 kg per ha). With 40-cm spacing, nearly 100 kg per ha of yield was lost, but 10 kg per ha seed was saved compared with 20-cm spacing (Fig. 2). In areas where winter and early spring months are as cold as it was in the year of 2003, the row spacing should be narrowed in order to get sufficient number of seedlings at low seed rates. Munzur et al. (1995) found optimum seed per square meter to be more than we found for 17.5 cm; nonetheless, the plant material they used was shorter in plant height, with less branching capacity and stretching properties than the hairy vetch. Two uses of cultivator operations should be considered for economic production, as the higher cost and shortage of labor and the short working period in spring inevitably necessitate mechanical weeding in practice (Meyveci et al., 1993).

Table IV. Mean values and statistical parameters of yield components of cv. Munzur 98 grown under different seeding rates and row spacings in rotation with wheat.

Spacing + Rates	Plant number per square meter	Branch number per plant	Pod number per branch	Kernel number per pod	1000 kernel weight (g)	Biomass (g/per square meter)	Harvest index (%)	Plant height (cm)
45 + 100	43.9	1.5	25.1	2.3	36.8	329.2	31.5	81.2
45 + 200	66.5	1.3	26.8	2.3	35.8	468.3	31.0	73.9
45 + 300	70.4	1.3	13.8	3.0	37.1	451.6	30.2	76.3
45 + 400	69.0	1.4	15.2	2.5	36.1	433.6	30.0	82.2
45 + 500	73.2	1.4	19.5	2.3	35.9	406.6	30.9	82.4
Averages	64.6	1.4	20.1	2.5	36.3	417.9	30.7	79.2
60 + 100	62.7	1.3	16.5	2.3	37.4	398.3	32.5	78.7
60 + 200	96.6	1.2	17.1	1.7	37.8	455.1	27.7	86.8
60 + 300	81.4	1.2	16.3	1.8	38.7	439.8	28.1	77.2
60 + 400	87.0	1.2	11.0	1.9	39.9	462.8	25.3	74.3
60 + 500	78.2	1.2	9.8	2.6	39.1	454.4	24.2	71.6
Averages	81.2	1.2	14.1	2.1	38.6	442.1	27.6	77.7
Probabilities (F tests)								
Year	0.003	0.000	0.010	0.054	0.114	0.000	0.000	0.000
Rep (Year)	0.019	0.000	0.640	0.752	0.586	0.580	0.082	0.387
Row spacing	0.005	0.002	0.053	0.162	0.093	0.197	0.003	0.523
Row spacing × year	0.340	0.000	0.152	0.339	0.652	0.004	0.294	0.002
Seeding rate	0.007	0.675	0.032	0.885	0.898	0.007	0.101	0.960
Seeding rate × Year	0.000	0.025	0.844	0.308	0.447	0.091	0.732	0.133
Seeding rate × row spacing	0.591	0.996	0.306	0.590	0.797	0.475	0.271	0.323
Seeding rate × row spacing × year	0.495	0.456	0.921	0.584	0.839	0.336	0.433	0.548
Least Significant Differences, LSD, (0.05)								
Row spacing	9.23	0.07	6.07	0.68	2.76	40.78	1.58	5.45
Seeding rate	15.88	0.25	6.69	0.98	2.83	54.71	3.56	12.00
Seeding rates in the same row spacing	10.79	0.17	4.54	0.67	1.92	37.17	2.42	8.16
Seeding rates in different row spacings	35.58	1.11	9.36	1.82	3.69	93.96	10.48	34.51
Coefficient of Variation, % (CV)								
Main plots	24.5	10.0	68.8	57.9	14.3	18.4	10.5	13.5
Subplots	31.5	29.1	36.4	58.5	8.1	20.5	18.4	21.3

3.2. Yield components

Seeding rates, row spacing and the seeding rate × year interaction significantly ($P < 0.01$) affected number of plants per square meter. More plants were obtained with 60-cm spacing and with increased seed rates than other treatments. Responses to seed rates differed with the year (seeding rate × year). In 2003, the response was linear, but it was quadratic in other years. This suggests that more seed is needed for areas with a cold winter and wet season, to obtain the same stand as in normal and dry years.

Branch number per plant was significantly influenced by row spacing and the row spacing × year and seeding rate × year interactions. Row spacing of 60 cm reduced the number of branches per plant by 14%; from 1.4 to 1.2. When the seed rate was increased, there was an increase in branch number in the dry year, but a decrease in the normal year. In the dry year, the number of branches was increased in wide row spacing, possibly because of more available soil water in 60-cm than 45-cm

spacing. However, it did not change in the wet year with a cold winter (2003), decreased in the normal year and increased in the dry and warm year (2001) with respect to increasing seed rates. High branching capacity at low seed rates was observed in the wet year and it rapidly dropped with increased seed rates and number of plants to a certain level. In the normal year, branch number was reduced with increasing seed rates as expected.

Pod number per branch was significantly influenced by seeding rates ($P < 0.05$) and row spacing ($P \approx 0.05$). As row spacing and seed rates increased, the pod number declined by 30%.

Grain numbers per pod were higher (16%) with 45-cm than 60-cm row spacing, while 1000 kernel weight was higher (6%) with 60 cm, but it was not statistically significant and not influenced by row spacing, seeding rate or the seeding rate × row spacing interaction.

Only the row spacing × year interaction was significant for biomass due to differential response to changing years. The biomass increased with wide spacing in 2002, was unchanged in

Table V. Direct and indirect effects of yield components on grain yields in path analysis.

Components*	Plants per square meter	Branches per plant	Pods per branch	Kernels per pod	1000 kernel weight	Yield
Plants per square meter	<u>0.26</u> *	0.44	-0.21	-0.14	-0.40	-0.04
Branches per plant	-0.23	<u>-0.49</u>	0.19	0.13	0.50	0.10
Pods per branch	-0.15	-0.26	<u>0.36</u>	-0.03	0.52	0.45
Seeds per pod	-0.13	-0.23	-0.04	<u>0.27</u>	0.28	0.15
1000 kernel weight	0.14	0.33	-0.26	-0.10	<u>-0.74</u>	-0.63

* Direct effects are underlined.

Table VI. Direct and indirect effects of yield components on 1000 kernel weight in path analysis.

Components*	Plants per square meter	Branches per plant	Pods per branch	Kernels per pod	Harvest index	1000 kernel weight
Plants per square meter	<u>0.46</u>	-0.28	0.07	-0.54	-0.09	-0.38
Branches per plant	0.52	<u>-0.32</u>	-0.72	0.05	-0.24	-0.71
Pods per branch	0.82	-0.59	<u>-0.39</u>	-0.26	-0.26	-0.67
Kernels per pod	-0.92	0.53	0.41	<u>0.27</u>	0.24	0.53
Harvest index	0.62	-0.44	-0.51	-0.14	<u>-0.35</u>	-0.81

* Direct effects are underlined.

Table VII. Direct and indirect effects of some components on harvest index in path analysis.

Components*	Biomass	Pods per branch	Kernels per pod	Harvest index
Biomass	<u>-0.25</u>	-0.28	-0.02	-0.55
Pods per branch	0.11	<u>0.61</u>	-0.03	0.70
Kernels per pod	<u>0.02</u>	-0.06	<u>0.29</u>	0.25

* Direct effects are underlined.

2001 and was reduced slightly in 2003. The plant height response to changing seeding rate and row spacing was the same as biomass.

The harvest index was 10% higher on plots with 45-cm than 60-cm row spacing. Seeding rate and the seeding rate $\times$ row spacing interaction did not make any significant change in the harvest index.

3.3. Correlation analysis

The correlations of grain yield with yield components were moderate but highest and negative ($r = -0.63$) with 1000 kernel weight. It was followed by positive correlation with pods per branch ($r = 0.45$) (Tab. V).

Correlations of 1000 kernel weight with yield components were higher than those of grain yields with yield components. They were all negative, except positive and moderate correlation with kernels per pod (Tab. VI).

Biomass had high positive and high negative correlations with plants per square meter and branches per plant, respec-

Table VIII. Direct and indirect effects of yield components on biomass in path analysis.

Components*	Plants per square meter	Branches per plant	Biomass
Plants per square meter	0.22	0.54	0.77
Branches per plant	-0.20	<u>-0.60</u>	-0.80

* Direct effects are underlined.

tively. Harvest index was largely and positively correlated ($r = 0.70$) with pods per branch (Tabs. VII and VIII).

3.4. Path analysis

3.4.1. Grain yield

Plants per square meter contributed positively to grain yield as a direct effect and indirect effect via branches per plant. Although the indirect effect was not so high (0.44), it was double the direct effect. Other components via plants per square meter showed a small and negative impact on grain yield except for the positive and small influence of 1000 kernel weight. On the other hand, branches per plant and pods per branch had a particularly positive and relatively high effect on grain yield via 1000 kernel weight. 1000 kernel weight had the highest negative direct effect on grain yield (Tab. V).

3.4.2. 1000 kernel weight

Plants per square meter had a positive direct influence (0.46) on 1000 kernel weight; however, it had negative effects (-0.54) via kernels per pod and via branches per plant (-0.28). On the other hand, plants per square meter had a negligible effect via

Pods per branch and via harvest index. Other components via plants per square meter had large positive influences on 1000 kernel weight except for a high negative effect with kernels per pod (Tab. VI).

3.4.3. Harvest index

Biomass directly and indirectly (via pods per branch) showed little but equal negative impacts on harvest index. Pods per branch and kernels per pod had direct and positive influences on harvest index but the effect of the former was about double that of the latter. Other components and paths had very small influences (Tab. VII).

3.4.4. Biomass

Biomass was positively influenced by the indirect effect of plants per square meter via branches per plant, which was double the direct effect of plants per square meter. However, branches per plant had a small negative indirect effect via plants per square meter and a comparatively high negative direct effect on biomass (Tab. VIII).

Except for its direct effect, 1000 kernel weight had positive interactions with other components in terms of grain yields. It was largely and positively influenced by pods per branch and harvest index via plants per square meter. However, there was a high negative effect of kernels per pod via plants per square meter on 1000 kernel weight.

Path analysis separated two groups of paths which had comparatively high effects on grain yields. The first group consisted of three indirect positive effects, which were plants per square meter via branches per plant, branches per plant via 1000 kernel weight and pods per branch via 1000 kernel weight. The second group was composed of negative effects which were direct effects of 1000 kernel weight and branches per plant.

4. CONCLUSION

Spacing and rates of seeding significantly affected the plants per square meter and branches per plant which led to the formation of the grain yields through the interrelations of two groups of positive and negative effects disclosed by the path analysis. The first group positively affected grain yield and consisted of three indirect effects of plants per square meter via

branches per plant, branches per plant via 1000 kernel weight and pods per branch via 1000 kernel weight. The other group negatively affected grain yield and was composed of the direct effects of 1000 kernel weight and branches per plant. The maximum and economic seed rates were 232 and 208 seeds per square meter, respectively, for spacing of 40 cm, which is the common practice throughout Central Anatolia in Turkey.

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