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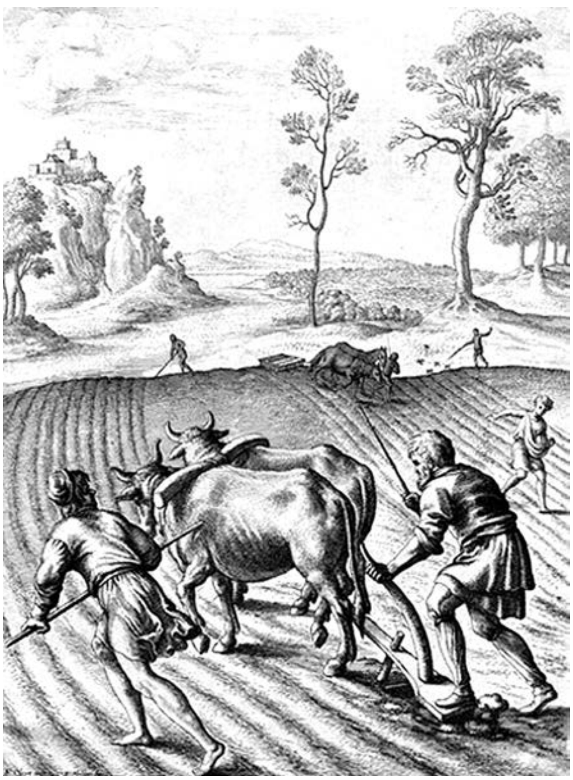

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Agronomical and Economical Assessment of Planting Methods and Seeding Rates in Irrigated Wheat (*Triticum aestivum* L.)

Mohammad Reza Mehrvar and Hormoz Asadi
Department of Cereals Research, Seed and Plant Improvement Institute,
Agricultural Research and Education Organization. Ministry of Jihad-e-Agriculture, Iran

Abstract: The experiment was conducted for crop seasons 2000-01 and 2001-02 in experimental farm of seed and plant improvement institute (SPII) in Karaj to compare effects of different planting methods of Reform (traditional), Hamedan Machine Barzegar (HMB, Conventional) and Rolling (Recently grain drill) in seeding rates of 80, 110, 140, 170 and 200 kg ha^{-1} in bread wheat cv. Pishtaz. The experimental design was RCBD in split-plot arrangement with three replicates. What made different between the used methods was their homogeneity in planting seeds in soil achieving better stand establishment and yield. This homogeneity was at least in Reform seeder because of making furrows after planting seeds in leveled land. While this homogeneity fulfilled in the best way through using Rolling method achieving maximum grain and straw yield. Results showed that two major yield components of spike No. m^{-2} and kernel No. m^{-2} were the most effective parameters reaching yield potential of the studied cultivar. Due to the significant interaction of the studied factors the best seeding rates for the planting methods were 140 kg ha^{-1} for Reform and 110 kg ha^{-1} for HMB and Rolling seeders showing seed use reduction of 30 kg ha^{-1}. Based on the results of economic analysis, the Rolling method and seeding rate of 110 kg ha^{-1} had the highest net income and the lowest cost comparing other treatments. So the rolling grain drill and seeding rate of 110 kg ha^{-1} was the best treatment. The mean production cost and net income of this treatment was $1268 and $597 ha^{-1}, respectively.

Key words: Wheat, planting method, seed rate

INTRODUCTION

Irrigated Wheat (*Triticum aestivum* L.) is grown on about 2.5 million ha in Iran. Despite the availability of HYVs of irrigated wheat for four main selection mega environments, the average irrigated wheat grain yield in the country is approximately 3800 kg ha^{-1} (Anomymous, 2003). Lower wheat grain yield could be due to production practices such as unsuitable seedbed preparation, delay in planting and inappropriate planting method. The selection of suitable planting method plays an important role in seed placement at proper depth and uniform seed distribution, creating better seed to soil contact, faster plant emergence and more homogenous plant stand. In Iran wheat is planted with different planting methods depending upon availability of planting machine, turn around time, the available soil water and previous crop. Irrigated wheat is planted mainly through flat planting by fertilizer spreaders and following bed formation on a large area after fallow or harvesting of a summer crop such as corn. Flat planting along with following bed formation not only requires higher seed rate but also results in lower plant population due to planting seeds in different depths randomly scattered in the soil with lower seed to soil contact resulting less emerged seeds per unit area. While drilling method, dominantly used in some provinces of Iran (Afzalnia *et al*., 2003), because of its uniform seed distribution and pattern on top of the beds and at desired depth usually results in higher germination and uniform stands and can be suggested as a recommended method. Previous research showed that due to better crop stand establishment, wheat grain yield is significantly affected by the different planting methods including broadcast and line sowing (Singh and Singh, 1992). Many researchers favored line/row sowing (Brown, 2000; Mulay *et al*., 1991; Hossain and Maniruzzaman, 1992; Sharma, 1992) but some recommended broadcast sowing because of speedy and timely sowing (Collins and Fowler, 1992) and higher net profit (Kumar and Tripathi, 1991). Higher grain yield from line sowing compared to broadcast sowing reported by Singh and Singh (1992) and Singh *et al*. (1993). Keisling *et al*. (1997) reported that grain yields of broadcast incorporated (BI) and drilled into prepared

Corresponding Author: Mohammad Reza Mehrvar, Department of Cereals Research, Seed and Plant Improvement Institute, Agricultural Research and Education Organization. Ministry of Jihad-e-Agriculture, Iran

seedbed (DP) methods were rather similar and were higher to the other methods of drilled no-till (DN)and broadcast unincorporated (BU). BI had the highest average net returns followed by DP. The economics of production indicated that total expenses were similar for DP, DN and BI except for varied seeding rates. Previous research has demonstrated the benefits of BI seeding including improved labor distribution, timeliness and reduced labor requirements (Collins and Fowler, 1992). Nonetheless, poor stand establishment has been the primary problem associated with BI seeding of wheat in research studies in Canada (Collins and Fowler, 1992; Barnett and Comeau, 1980). Larson and Watson (2005) reported BI planting method makes random seeding depth not firming soil around the seeds causing less plant emergence than with drilled seed. So higher seeding rates to offset moderate emergence success and to use Culti-packer to firm the seedbed possibly improve stand establishment were suggested. Brown (2000) reported that drilling with press wheels hastened emergence, with final stands reached in about 2.5 weeks while drilling without press wheels significantly delayed emergence. Also there was no yield interaction between seeding method and seed rate and broadcast seeding reduced yield due to delayed emergence and increased seeding rates (180 lb per acre) did not compensate and improve yield regardless of seeding method.

This study was conducted to compare agronomical and economical parameters of the previous grain drills with the Rolling grain drill as a recently made planting system in different seeding rates.

MATERIALS AND METHODS

The study was conducted for crop seasons 2000-01 and 2001-02 at Research experimental fields of seed and plant improvement institute (SPII) in Karaj located in Southwest of Tehran. The experiment consisted of three planting methods of Reform grain drill sowing on prepared flat seedbed then forming beds, Hamedan Machine Barzegar forming beds and drilling seeds on top or the slopes of the beds, Rolling seeder with simultaneous forming beds and drilling seeds on top of the beds then firming beds with press wheels and five seeding rates of 80, 110, 140, 170 and 200 kg ha^{-1} with three replications in Randomized Complete Block Design with split plot arrangements. The planting methods and seeding rates were assigned to the main and subplots, respectively. Recommended doses of nitrogen and phosphorus fertilizers were applied as one third of the total recommended rate at the time of planting, late tillering and booting growth stages. Irrigations were given according to the requirements of crop. Weed control was done with spraying Puma super™ and Granstar™ controlling the grassy and broadleaf weeds, respectively. Data recorded for heads and kernels per m^{-2}, grains per spike, 1000 grain wt (g), biological yield (kg ha^{-1}) and economical (grain) and straw yield (kg ha^{-1}) recorded from a sample of rows of the two central beds 1m in length from each plot. The number of grains per spike was calculated by counting grains of 20 randomly selected spikes from each sample adjusting for the average number of grains per spike. Grain weight was recorded by weighing 1000 grains from each seed sample prepared from the harvested sample area after threshing and cleaning. Straw weight was recorded by subtracting grain weight from the sample sun dried weight for each treatment then converted into kg ha^{-1}. An experimental combine Wintersteiger® was used for the final harvest area in each plot. The wheat grain moisture contents were determined by an individual plot sample from each plot and grain yields were adjusted to constant 10 % moisture content. Yield components of spike No. m^{-2}, kernels per spikeand kernel weight were determined by plants from harvested sample of the 1 m rows of the two central beds in each plot. Wheat variety Pishtaz was sown either in lines with a row spacing of 11 cm including 3 rows on top of each bed (with 51 cm width) in Rolling and Reform planting methods. In Reform method with randomly scattered seeds on the soil surface due to the following forming beds (with 60 cm width) there were 21 rows in 2.5 m width of the grain drill. But HMB planting method included 4 rows with 15 cm spacing on each bed with 60 cm width. The number of productive spikes was counted in a sample prepared from each plot adjusted for 1 m square which was weighed after being sun dried and reaching constant weight. F-test was used to detect the significance of treatments effect and the DMRT was applied for means comparison.

The main purposes of this study were, agronomical and economical comparison of new planting method with the previous methods in different seeding rates and to determine production cost, gross and net income of different treatments and Substitution of different treatments choosing the best treatment. The economical methodologies of this study were as partial budgeting technique used to estimate production cost in different planting methods and seeding rates. The grain and straw yield and their price were used to estimate gross income of the treatments. Then the mean of cost and gross income change arising from substitution of different treatments were used for their profit and ultimately treatments were compared one by one to choose the best treatment. Trend analysis (Gomes and Gomes, 1983) was also conducted to determine the linear, quadratic or cubic response of crop parameters to seed rate treatments.

Table 1: Combined ANOVA for the studied characteristics affected by planting methods, seeding rated and their interaction

		M.S.						
SOV	DF	Kernel no. Spike^{-1}	Kernel No. m^{-2}	Biological yield (kg ha^{-1})	TKW (g)	Straw yield (kg ha^{-1})	Spike No m^{-2}	Grain Yield
Year (Y)	1	3436.389**	108739465.652**	7.04**	1088.544**	0.588ns	5104621.555**	4.139**
Replicate (Y)	4	77.123ns	9428770.872*	2.321*	9.996ns	0.506ns	8205.032**	0.743*
Planting method (A)	2	77.85ns	133949094.57**	101.183**	6.423ns	50.934**	6377.158*	18.169**
YA	2	51.19ns	3405888.451ns	31.39**	2.85ns	27.859**	16436.497**	2.784**
Error	8	26.056	2210234.179	0.526	5.445	0.174	1233.091	0.195
Seeding rate (B)	4	79.872**	28896065.139**	19.704**	6.333*	3.873**	54976.164**	2.002**
Linear	1	167.7**	5312000	0.714	0.2	0	75347**	2.561
Quadratic	1	116.31	96410000**	74.0567**	13.349**	14.8687**	30756	4.4701**
Deviations	2	17.74	6930000	2.022	5.892	0.311	56901	0.488
YB	4	11.123ns	11391290.124**	3.3**	7.489*	0.628**	19635.057*	1.843**
AB	8	16.992ns	4406197.055**	2.132**	3.829ns	0.401*	18989.249**	1.144**
YAB	8	33.185*	4555398.765**	1.353*	5.194*	0.303ns	25612.961**	0.348ns
Error	48	13.120	1146569.609	0.586	2.353	0.179	6579.678	0.175

NS: Non Significant; *,**Significant at p<0.05 and p<0.01 levels, respectively

Table 2: Mean comparison for studied traits affected by planning methods and seeding rates in two crop seasons of 2000 and 2001

Treatments	Grain yield (kg ha^{-1})	Stubble yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Spike No. m^{-2}	Seed No. spike^{-2}	TKW (g)	Seed No. m^{-2}
Planting method							
a1 (Reform)	7839c	8566b	15984b	767b	24a	43.6a	16622b
a2 (HMB*)	8311b	7043c	14985c	763b	26a	44.5a	17788b
a3 (Rolling)	9360a	9636a	18545a	791a	27a	44.0a	20723a
Seeding rate (kg ha^{-1})							
b1 (80)	8403b	7960c	15627c	716b	26a	43.7b	17548c
b2 (110)	8939a	8554b	16837b	752b	28a	43.9ab	19070b
b3 (140)	8658b	9033a	17924a	854a	26a	44.2ab	20385a
b4 (170)	8483b	8585b	16810b	753b	26a	44.9a	18536b
b5 (200)	8034c	7942c	15325c	799a	23b	43.3b	17308c
Planting method x seeding rate							
a1b1	7710f	8029c	14947de	745bcdef	23bcd	43bcd	15487fg
a1b2	7883ef	8564d	15920c	703ef	28a	43d	16819ef
a1b3	8540cd	9435b	18049b	841ab	25abc	43cd	19734bc
a1b4	7935ef	8852cd	16401c	824acd	23bcd	45ab	16188ef
a1b5	7128g	7948e	14603c	724def	20d	44bcd	14877g
a2b1	7920ef	6640h	14085c	711ef	28a	44abcd	16885c
a2b2	8660cd	6919gh	14758c	720def	27ab	45abc	17523de
a2b3	8410de	7520ef	16260c	836abc	27ab	46a	19285bc
a2b4	8620cd	7377fg	15782cd	704ef	27ab	45abc	18490cd
a2b5	7947ef	6759h	14038c	845ab	21cd	43cd	16764ef
a3b1	9578b	9212bc	17849b	682f	28a	44bcd	20185b
a3b2	10273a	10179a	19832a	806abcde	28a	44abcd	22340a
a3b3	9023c	10143a	19463a	874a	26ab	44abcd	21660a
a3b4	8895cd	9527b	18247b	734cdef	28a	44abcd	20175b
a3b5	9028c	9118bc	17335b	858a	25abc	44bcd	19256bc

*Hamedan Machine Barzegar (HMB); Columns sharing the same letter(s) indicate non-significant differences

RESULTS AND DISCUSSION

As the Table 1 shows the year had significant effect on all characteristics except straw yield. Also planting methods had significant effect on grain yield, biological yield, straw yield, spike No. m^{-2}, kernel No. spike^{-1} and kernel No. m^{-2} (Table 1). There was a significant effect of seed rate on all studied parameters with linear trend for kernel number per spike and spike number per unit area and quadratic trend for kernel number per unit area, 1000 kernel weight, biomass and grain and straw yield. This means that the grain and straw yield would be diminished when planting the variety out of the optimum seeding rate. These results agree with the findings of Attarde and Khuspe (1989), Rajput *et al.* (1989) and Khan *et al.* (2002). Therefore using optimum seeding rate is necessary to reach biomass and grain yield potential. Also the data in Table 2 showed that higher seeding rates (>170 kg ha^{-1}) did not improve grain yield regardless of planting method. The interaction of year and seed rate was significant for all studied parameters except kernel number per spike suggesting separate seed rate for each planting method. According to agronomy results (Table 1), the seeding rate of 140 kg ha^{-1} for Reform and 110 kg ha^{-1} for HMB and Rolling methods were recommended to get the highest grain yield. But for the rolling method the seeding rate of 110 kg ha^{-1} was the best treatment combination to get both the maximum grain and straw yield. In cab be concluded that to reach the yield potential of high yielding varieties of irrigated wheat supplying dry matter demanded by the grains in the grain filling period is necessary through production of higher leaf area and net assimilation rate (Table 2).

At harvest time spike No. m^{-2} was significantly higher with Rolling as compared to HMB and Reform methods (Table 2) which may be attributed to more number of fertile tillers in Rolling method. Biological yield was also significantly higher in Rolling method.

The superiority of drilling to the broadcast sowing method has been reported by Fenech and Papy (1977), Shaalan *et al.* (1977), Singh and Singh (1992), Tanveer *et al.* (2003). Afzalinia *et al*. (2003) stated that among the tested grain drills, Nordstone had the maximum grain yieldand the broadcast sowing method had the minimum grain yield while between the grain drills, Machine Barzegar Hamedan had the least grain yield.

The grain yield is a function of interaction between genetic and environmental factors like soil type, sowing time and method, seed rate, fertilizers and time of irrigation. Among the environmental factors influencing grain yield potential, row spacing plays a vital role obtaining higher grain yield. Also based on the data shown in Table 2 increasing seeding rate caused limitation for grain, biological and straw yield in both Reform and HMB planting methods. This can be attributed to the special planting architecture in Rolling method from the points of planting seeds in narrower rows (11 cm) with more seed bed utilization, homogeneity in completing growth stages in adjacent rows due to planting seeds on top of the beds similar to the raised bed planting system and less interplant competition due to lesser amount of seed rates. So with the usage of a suitable drilling technique there is no need to increase the seed rate to compensate the grain yield reduction while this could lead to obtain more straw yield which may be sometimes more economical for the farmers than grain. The higher grain yield in the Rolling method can be attributed to the higher significant spike and kernel number per unit area. Meanwhile there are many advantages using Rolling method such as planting seeds in narrower rows (11 cm row spacing) comparing to the rows made by the HMB planting method (15.5 cm), faster plants emergence (about 4 days), lower amount of runoff water in the furrows and probably faster soil warming due to making shallow furrows (about 15 cm in height) and planting seeds on top of the beds (raised bed wheat) with the advantages of bed and furrow method improving mechanical weed control, water and fertilizer use efficiencies and ease in water and fertilizer application (Sayre and Momeo Ramos, 1997; Hobbs *et al*., 1998). Planting seeds in narrower rows may cause more beneficial inter-row competition which helps reaching wheat yield potential when using less seeds in the rows to minimize the intra-row competition, better planting pattern and probably more light use efficiency because of less competition. Another advantage for the new Rolling grain drill is to make a better seed to soil contact by the press wheels mounted in the rear of the machine which has no interference with the sowing seeds and forming beds. This seemed to be the reason for the faster plant emergence in Rolling planting method comparing to the other planting methods. So, in order to have a good plant stand in HMB grain drill the soil should be well prepared but not in rolling method due to less impact between the openers and seeding devices with the soil along with then press wheels in the rear of the machine firming soil and shaping beds properly. According to the results the Rolling method can be beneficial for the farmer not only from the point of more grain and straw yield but also from the point of reducing the amount of seed (about 30 kg ha^{-1} seed use reduction) and irrigation water allowing to irrigate more area with a constant amount of water through minimizing height of the beds to about 15 cm which is more in the other methods especially the Reform method with beds of more than 20 cm height. The Rolling method had the highest plants germinated followed by the HMB and Reform. Higher emergence with the Rolling method could be due to the sowing at uniform depth and suitable seeding rate. But the bed formation after sowing seeds with Reform grain drill could have resulted in the placement of seed deeper and plants randomly emerged on the surface of the soil, in the furrows, on top or the slope of the beds causing plant emergence in different times and subsequent different growth phases making negative competition. According to the data using a suitable grain drill would create a positive coordination between the yield components of kernel and spike number per unit area leading to the maximum grain, straw and biological yield (Liu *et al*., 1994). The production of greater yielding components of wheat can be attributed to improved light penetration (Chang *et al*., 1991) and utilization because of the well-spaced plant population. Line sowing produced higher grain and straw yield, greater harvest index and greater yielding components than broadcast sowing.

Heydarpour *et al.* (2006) compared Nordstone drilling with flood irrigation; broadcasting seeds with fertilizer spreader along with disking and flood irrigation; drilling with HMB then furrow irrigation and hand seed broadcasting then chisel and furrow irrigation in south west of Iran on irrigated wheat cv. Falat (Seri 82) in constant density of 450 seeds per square meter. The results showed the germinated seeds percentage was the only parameter significantly affected by the planting methods but not for the grain yield and yield components of spike number, thousand kernel weight and kernel number per spike. The highest germinated seeds belonged to the HMB planting method and the lowest to the hand seed broadcasting and the Nordstone drilling with flood irrigation with the highest grain yield was the treatment recommended.

Khan *et al.* (2002) believe optimum seed rate is most important for maximum yield of crop and in case of using more seed rate plant population will be more and there will be competition among plants for water, nutrients and sunlight resulting in low quality and low yield. While using less seed rate may cause yield loss due to lesser number of plants per unit area (Attarde and Khuspe, 1989). This seems a logical deduction especially for the varieties with low tillering behavior but for the CIMMYT origin wheat varieties with high tillering capacities the field gaps can be filled in lesser amounts planted seeds. Esechie *et al.* (2002) reported that grain yield increased as seeding rate increased, the largest grain yield was obtained at 120 kg ha^{-1} seeding rate, but was not significantly different from the 90 kg ha^{-1} seeding rate. Qaisar (1991) compared different seeding rates and reported the highest grain yield with 100 kg seed ha^{-2}. Singh *et al.* (1993) reported that seeding rates of 100, 125 and 150 kg ha^{-1} gave average grain yield. Urmani *et al.* (1974) reported that wheat seeding rate of 100-125 kg ha^{-1} gave higher grain yield than sown at 75 kg ha^{-1}, while the highest grain yield was obtained with seeding rate of 100 kg ha^{-1}. Mujahid (1972), reported the seed rate had a significant effect on grain yield and maximum grain yield (2345.90 kg ha^{-1}) was noted in 150 kg ha^{-1} seed rate, while minimum grain yield (1675.57 kg ha^{-1}) was recorded for 50 kg ha^{-1} seeded plots. These results coincide with the results of this experiment. On the contrary Rajput *et al.* (1989) concluded that maximum grain yield was obtained with the increase in seed rate, while minimum grain yield was produced by low seed rate.

Shaalan *et al.* (1977) reported that 1000-grain weight was higher in drill sown wheat than broadcasted wheat. Esechie *et al.* (2002) reported that in three irrigated wheat cultivars 1000-kernel weight (TKW) decreased with increasing seeding rate. One thousand kernel weight showed slight decrease with increase in seed rate (Giotard *et al.*, 1981). Kovac (1978) found that increase in seed rate decreased 1000 kernel weight. Mujahid (1972), reported heavier seeds (44.25 g per 1000 kernels) at seed rate of 50 kg ha^{-1} while lighter seeds (40.12 g per 1000 kernels) observed at the rate of 150 kg ha^{-1}. On the contrary the effect of planting method on the 1000 kernel weight was not significant that may be the result of coordination among kernel number per spike and unit area and spike number per unit area.

Tanveer *et al.*, (2003) reported that at harvesting, number of spikes per meter square was higher with BCB (Broadcasting + bed formation) and BDS (bed formation + drill sowing) planting method as compared to (BC) broadcasting and (DS) drill sowing methods. Shaalan *et al.* (1977) reported that spikes m^{-2} was higher in drill-sown wheat than broadcasted wheat. Jan *et al.* (2001) reported that Line sowing had significantly more spike population than broadcast sowing.

Tanveer *et al.*, (2003) reported that number of kernels per spike was significantly higher in raised bed wheat (broadcasted and drilled beds) in comparison with the flat sown wheat (broadcasting and drill sowing). Shaalan *et al.* (1977) reported that number of kernels per spike was higher in drill-sown wheat than broadcasted wheat. Jan *et al.* (2001) reported the superiority of line sowing to broadcast sowing which had significantly more kernels per spike. Esechie *et al.* (2002) reported that in three irrigated wheat cultivars number of kernels per spike did not respond to seeding rate. The number of kernels per spike showed slight decrease with increase in seed rate (Giotard *et al.*, 1981).

Due to the significant interaction effects of the year and planting method on grain, straw and biomass and spike number per unit area the yield component of spike number per unit area plays a critical role obtaining grain and straw yield potential of wheat. Previous reports indicated the superiority of grain drills to the other planting methods to get the higher grain yield while using the best grain drill is also a necessity to reach grain yield potential of high yielding varieties of wheat. In fact the farmer should make decision based on limitations such as speedy and timely planting operations, seedbed formation and firming soil while minimizing production costs (Table 3). Also the data shows that using a suitable grain drill would create a positive coordination between the yield components of kernel and spike number per unit area leading to the maximum grain, straw and biological yield (Liu *et al.*, 1994).

Excluding the cost of seed, the mean cost of production for planting methods, Reform (traditional), HMB (conventional) and Rolling (new) were estimated 1318, 1435 and 1268 US$ ha^{-1}, respectively (Table 4). In Reform planting method, the share of cost of production including seed bed preparation (plow, disk,...), planting, production practices, harvesting and seed cleaning and depreciation of seeders were estimated 6.5,10.5, 55, 14 and

14 %, respectively. In HMB planting method, the share of cost of production including seed bed preparation (plow, disk,...), planting, production practices, harvesting, seed cleaning and depreciation of seeders were estimated 6.1, 4.8, 50.5, 12.8 and 25.8 %, respectively. In Rolling planting method, the share of cost of production including seed bed preparation (plow, disk,...), planting, production practices, harvesting and seed cleaning and depreciation of seeders were estimated 6.9, 5.4, 57.1, 14.5 and 16.1%, respectively. Afzalinia **et al.** (2003) evaluated performance of the most grain drills in Iran and showed that the highest crop yield (8254.5 kg ha^{-1}), crop value (1020.56 CND ha^{-1}), net benefit (1024.06 CND ha^{-1}) and benefit to cost ratio (3086) belonged to the Nordstone

Table 3: Production cost of irrigated wheat in different planting methods

	Reform (Traditional)			Hamedan machine barzegar (Conventional)			Rolling (New)		
Costs*	Year 2000	Year 2001	Mean	Year 2000	Year 2001	Mean	Year 2000	Year 2001	Mean
Seed bed preparation (plow, disk, ...)	80	95	87.5	80	95	87.5	80	95	87.5
Planting	126	150	138.0	63	75	69.0	63	75	69.0
Production practices	662	786	724.0	662	786	724.0	662	786	724.0
Harvesting and seed cleaning	168	200	184.0	168	200	184.0	168	200	184.0
Depreciation of seeders	183	187	185.0	366	375	370.5	201	206	203.5
Total cost	1219	1418	1318.5	1339	1531	1435.0	1175	1362	1268.0

Source: experimental data; * Each US$/ha in years 2000 and 2001 were 8188 and 8008 rials in Iran, respectively

Table 4: The mean of wheat grain yield and benefit and cost of treatments in different planting methods

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Production cost (US$/ha**)	Gross income (US$/ha)	Profit (US$/ha)
a1b1	7709.0	8029.0	1329	1437	108
a1b2	7884.0	8564.0	1334	1489	155
a1b3	8529.0	9435.5	1338	1495	157
a1b4	7924.5	8852.0	1342	1511	169
a1b5	7127.5	7948.5	1346	1348	2
a2b1	7920.0	6640.0	1446	1406	-40
a2b2	8660.5	6918.5	1450	1520	70
a2b3	8410.0	7520.0	1454	1516	62
a2b4	8619.5	7377.0	1459	1551	92
a2b5	7946.0	6758.5	1463	1413	-50
a3b1	9575.5	9214.0	1279	1746	461
a3b2	10273.5	10181.0	1283	1880	597
a3b3	9022.5	10140.0	1288	1711	423
a3b4	8894.5	9528.0	1292	1667	375
a3b5	9029.0	9118.0	1296	1666	370

Source: experimental data; * For planting methods, a1 (Reform), a2 (Hamedan Machine Barzegar), a3 (Rolling) and for seeding rates, b1 (80 kg ha^{-1}), b2 (110 kg ha^{-1}), b3 (140 kg ha^{-1}), b4 (170 kg ha^{-1}), b5 (200 kg ha^{-1}).**Average US$ for year 2000-2001 was equivalent to 8098 rials in Iran

Table 5: Substitution of treatments by a3b2 (Rolling method and seeding rate of 110 kg ha^{-1})

Treatments	The mean of gross income change arising from substitution (US$/ha**)	The mean of cost change arising from substitution (US$/ha)	Substitution of treatments by a3b2 treatment
a1b1	-443	46.0	Non-profitable
a1b2	-391	50.0	Non-profitable
a1b3	-262	55.0	Non-profitable
a1b4	-369	59.0	Non-profitable
a1b5	-533	63.0	Non-profitable
a2b1	-474	162.0	Non-profitable
a2b2	-360	167.0	Non-profitable
a2b3	-365	171.0	Non-profitable
a2b4	-329	175.0	Non-profitable
a2b5	-467	180.0	Non-profitable
a3b1	-134	-4.4	Non-profitable
a3b3	-169	4.4	Non-profitable
a3b4	-213	8.7	Non-profitable
a3b5	-214	13.0	Non-profitable

Source: experimental data; For planting methods, a1 (Reform), a2 (Hamedan Machine Barzegar), a3 (Rolling) and for seeding rates: b1, b2, b3, b4 and b5 as 80, 110, 140, 170 and 200 kg ha^{-1}, respectively. **Average in US$ for year 2000-2001 was equivalent to 8098 rials in Iran

Table 6. Comparing some characteristics of the grain drills used in this research

Grain drill	Type and number of openers	Row space (mm)	Effective operating width (mm)	Furrower	Press wheel
Hamedan machine barzegar (HMB)	Runner opener 20	155	3150	Yes	No
Reform	Runner opener 21	120	2550	No	No
Rolling	Runner opener 21	120	2550	Yes	Yes

grain drill comparing with HMB, Keshtgostar and broadcast sowing. While the economic evaluation parameters of the HMB including crop yield (7685.0 kg ha^{-1}), net benefit (954.85 CND ha^{-1}) and benefit to cost ratio (2493) was after the Nordstone grain drill but the best planting depth uniformity, the highest draft requirement due to the furrower availability and the maximum plants per unit area belonged to HMB and considered as a recommended grain drill for planting irrigated wheat.

In Reform planting method and seeding rate 140 kg ha^{-1} (a1b3 treatment) highest grain and straw yield were 8529 and 9435.5 kg ha^{-1}, respectively. The profit for this treatment was 157 US$ ha^{-1}. In HMB planting method and seeding rate 170 kg ha^{-1} (a2b4), highest grain and straw yield were 8619.5 and 7377 kg ha^{-1}, respectively. The profit for this treatment was 92 US$ ha^{-1}. In Rolling method and seeding rate 110 kg ha^{-1} (a3b2), the highest grain and straw yield were 10273.5 and 10181 kg ha^{-1}, respectively and its profit was 597 US$ ha^{-1} which was in maximum. According to the economical and agronomy results the best seeding rates for planting methods of Reform, HMB and Rolling were 140, 110 and 110 kg ha^{-1}, respectively and Rolling method and seeding rate of 110 kg ha^{-1} had the most profit and was the best. The mean net income and production cost of this treatment was 597 and 1283 (US$ ha^{-1}), respectively. According to Table 5, substitution of Rolling seeder and seeding rate 110 kg ha^{-1} (a3b2) treatment by other treatments was non- profitable, because income decrease was more than cost decrease (Table 5). Afzalinia *et al*., 2003 stated that Nordstone grain drill had the best benefits to costs ratio, so it was the most economic grain drill among the tested methods and HMB took the second place.

Table 6 shows some characteristics of the grain drills used in this research. One of the main reasons for the superiority of the rolling method is planting seeds in narrower rows (three rows on bed top in 11cm distance) comparing to the other studied methods (Table 6). This information shows seeds planted in narrower rows for Reform and Rolling drills compared to the HMB. While Rolling drill is equipped with the furrower and press wheels seemingly as two parts needed for increasing plants established ultimately leading more spike and seed number per unit area which are two key traits reaching grain and biological yield potential for irrigated wheat HYVs.

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