Impact of Row Spacing and Herbicide Rate and Application Method on Weed Control and Harvest Efficiency of Lima Bean

Sujatha Sankula,¹

Mark J. VanGessel,²

Walter E. Kee,³ and

J.L. Glancey⁴

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SUMMARY. Field studies were conducted in 1997 and 1998 to evaluate labeled (1×) or reduced (0.5×) rates of metolachlor plus imazethapyr preemergence either broadcast or band applications to lima bean (*Phaseolus lunatus* L.) planted in 30-inch (76-cm) or 15-inch (38-cm) rows for weed control, yield, harvestability, and harvest recovery. Lima bean was planted in large plots simulating a commercial production system. All 30-inch rows were cultivated once 40 days after planting in 1997 and 21 days after planting in 1998. No differences were noted in weed densities between treatments both years. Marketable lima bean yield was greater from plots that

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¹Postdoctoral research associate, Department of Plant and Soil Sciences, University of Delaware, Research and Education Center, Road 6, Box 48, Georgetown, DE 19947.

²Associate professor, Department of Plant and Soil Sciences, University of Delaware, Research and Education Center, Road 6, Box 48, Georgetown, DE 19947.

³Extension vegetable specialist, Department of Plant and Soil Sciences, University of Delaware, Research and Education Center, Road 6, Box 48, Georgetown, DE 19947.

⁴Associate professor, Department of Bioresources Engineering, University of Delaware, Newark, DE 19717.

were spaced 15 inches apart in 1997 only. However, total hand-harvested yield in both years, machine-harvested yield in 1998, and marketable yield in 1998 were not different between treatments. Measurements on harvest recovery revealed that a greater number of unstripped pods were left on plants after harvest in 15-inch row plots that were sprayed broadcast with 1x herbicide rate in 1997 only. Weight of beans lost per unit area and trash weight from 7-oz (200-g) bean sample was similar among treatments both years. Overall, weed control, yield, and harvest efficacy of lima bean was not impacted by row spacing, herbicide rate, or method of herbicide application in a commercial production system.

Green lima bean is a major processing crop in the mid-Atlantic region with 15,000 acres (6,100 ha) planted annually (Tarburton et al., 1995). In 1998, the latest year reported by the National Agricultural Statistics Service (U.S. Department of Agriculture, 1998), lima bean was planted on 13,000 acres (5,300 ha) in Delaware. Although there is considerable competition from other lima bean producing areas, those areas have limited acreage (Kee, 1986). Lima bean production in Delaware is challenging as yields on a per-acre basis are lower than other producing areas due to production issues related to soil type, pest control, harvest recovery, and harvest efficiency (Kee et al., 1997). Research on the impact of cropping practices on profitability, and implementing changes to make production more profitable will help maintain lima bean as a viable crop in Delaware.

Weed management is a primary concern to farmers for several reasons. Weeds compete with lima bean for water, nutrients, and light and can result in decreased yields. Glaze and Mullinix (1984) reported 18% yield loss with lima bean over a 3-year period with 0.25 sicklepod (*Senna obtusifolia* L.) plants/ft² (2.7 plants/m²).

The threshold for sicklepod is the only weed threshold established for lima bean (Glaze and Mullinix, 1984). Lima bean growers currently rely on preventive, soil-applied herbicides for weed control. Lima bean is routinely cultivated two to four times to improve weed control. Bentazon [3-(1-methyl ethyl)-(1H)-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide] and sethoxydim

{2-[1-(ethoxyimino) butyl]-5-[2-ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} are the only two postemergence (POST) herbicides labeled for lima bean. However, they control only a few broadleaf and grass weeds. Research is needed to identify alternatives or complementary methods to herbicides for lima bean that provide sufficient economic return to growers.

Reduced herbicide rates and band application of herbicides proved to be effective methods in reducing the total amount of herbicide used in the more competitive crops like corn (*Zea mays* L.) and soybean [*Glycine max*(L.) Merr.] (Buhler et al., 1992; DeFelice et al., 1989; Mulder and Doll, 1993). Cultivation used in combination with reduced herbicide rates or banded applications has improved total weed control in soybean and corn (Buhler et al., 1992; DeFelice et al., 1989; Gunsolus, 1990; Mulder and Doll, 1993). Yet, limited research has been conducted in less competitive crops such as lima bean. Reduced herbicide rates may be successful in less competitive crops when used in combination with other methods such as cultivation. Preemergence (PRE) herbicides may not provide season-long weed control and may require a POST application or a cultivation for additional weed control (Peters et al., 1965; Shaw et al., 1989; Wax et al., 1977).

Decreasing space between crop rows has been discussed as a strategy to reduce the need for herbicides (Patriquin, 1988; Teasdale and Frank, 1983). Narrow row crops may require less herbicide than wide row crops for equally effective weed control (Forcella et al., 1992). Crops grown in narrow rows [15 inches (38 cm) or less] shade weed seedlings more than those grown in traditional wide rows [30 inches (76 cm)] (Yelverton and Coble, 1991). Increasing seeding rate as row spacings decrease has not improved lima bean yields in the mid-Atlantic region (Sirait et al., 1994; Wootten, 1994).

Weedy fields reduce raw product recovery by harvesters and generate more trash in the harvested product. Research by Kee et al., (1997) revealed that trash content in harvested lima bean averaged 13% in a 2-year test period. Weeds reduce harvest efficiency and add costs during raw product preparation at the processing plant (Glancey et al., 1995). Weeds like horsenettle (*Solanum carolinense* L.), eastern black nightshade

(*Solanum ptycanthum* Dun.), and morningglory (*Ipomea* L.) produce berries or seeds similar in size or color to lima bean. The presence of these weed seeds, as well as other foreign materials, can result in a penalty or price reduction to the grower including outright seed rejection by the processor (Kee et al., 1997). Removing weed seeds and plant parts with the cleaning systems on the combines or with color sorters in the processing plant is difficult. At present, the best method to reduce weed seed contamination from the harvested product is an effective weed control program during the growing season (Glancey et al., 1997).

Poor harvest recovery represents a significant economic loss to lima bean growers and processors. On an average, >15% of the lima bean crop is left in the field after harvest with pod-stripper combines. More than 75% of the harvest loss occurs at the head of the combine where the pods are stripped from the plant. Losses during threshing and cleaning averaged <25% of the total harvest loss (Glancey et al., 1997). Three factors that effect lima bean recovery at the combine head are field levelness, relationship between combine ground speed and picking reel speed, and lima bean cultivar (Kee et al., 1997).

Kee and Glancey (1996) reported that lima bean cultivars with small plant type like 'Maffei-15' exhibited twice the head loss compared with cultivars having larger biomass. The higher head loss with smaller cultivars was attributed to the fundamental plant architecture in which a greater portion of the pod set is close to the ground. Previous research by Sirait et al. (1994) reported differences in pod set of the same lima bean cultivar planted under different row spacings. When planted in 15-inch rows, pods grew lower on the plant than in 30-inch rows, a response to high plant population density also observed in soybean (Hanway and Thompson, 1967). Conversely, growth habit of 'Maffei-15' lima bean was more upright with few pods set close to the ground in 15-inch rows than 30-inch rows (S. Sankula, M.J. VanGessel, K.L. Everts, and W.E. Kee, unpublished data).

Early research on lima bean evaluated the effect of a single independent variable on harvest and harvest recovery (Kee and Glancey, 1996). This study was initiated with a multifactor approach to evaluate the impact of different row spacings with labeled or reduced herbi-

Table 1. Preharvest weed counts in lima bean as influenced by row spacing, herbicide rate, and method of application in 1997 and 1998.^z

Row spacing [inches (cm)]	Treatment ^y	Weeds/ft ^{2x}	
		1997	1998
30 (76)	1× broadcast	3	0
15 (38)	1× broadcast	2	0.1
30 (76)	0.5× broadcast	1	0
15 (38)	0.5× broadcast	3	0
30 (76)	1× band	3	0.1
30 (76)	0.5× band	1	0.1
LSD _(0.05)		NS	NS

^zWeed density is total of broadleaf and grass weeds present on 17 Sept. 1997 and 28 Sept. 1998.

^yHerbicide applications comprised of 1× or 0.5× rates of metolachlor plus imazethapyr preemergence. The 1× rate applied broadcast spray or in a 10-inch (25-cm) band was 1.34 lb/acre (1.5 kg·ha⁻¹) metolachlor plus 0.045 lb/acre (0.05 kg·ha⁻¹) imazethapyr. Only 30-inch spaced rows were cultivated once, both years.

^x1 weed/ft² = 11 weeds/m².

cide rates, applied broadcast or banded on weed control, yield, and harvest efficiency of lima bean.

Materials and methods

Field experiments were conducted at University of Delaware's Warrington Farm located near Harbeson, Del., in 1997 and on a grower's farm near Dover, Del., in 1998. Soil was Downer loamy sand (coarse-loamy, siliceous, mesic, Typic Hapludults) in 1997 and Sassafras sandy loam (fine-loamy, siliceous, mesic, Typic Hapludults) in 1998. Soil pH was 5.4 in 1997 and 5.3 in 1998 with 1.2% and 1.4% organic matter, respectively.

'Maffei 15' lima bean was seeded on 27 July, 1997 and 13 July, 1998. Seeding depth was 1 to 1.2 inches (2.5 to 3 cm), and row spacings were 15 and 30 inches. Lima bean was planted in large plots to simulate a commercial production. Plot size was 30 × 689 ft (9 × 210 m) in 1997 and 30 × 886 ft (9 × 270 m) in 1998. Plots with 15-inch rows consisted of 14 planted rows while 30-inch rows had eight planted rows. Total plant population with 30-inch row spacings was 71,000 plants/acre (175,000 plants/ha) and 142,000 plants/acre (350,000 plants/ha) in 15-inch rows.

Metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide] plus imazethapyr [2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid] was applied either broadcast or as a band at 1× and 0.5× rates PRE [1.34 and 0.045 lb/acre (1.5 and 0.05 kg·ha⁻¹) of active ingredient, respectively, for the 1×] within 1 d of planting. This is the most common herbicide combination used for lima bean production in the

mid-Atlantic region. The 15-inch-spaced lima bean was sprayed only broadcast with the herbicide mixture while 30-inch rows received either a broadcast or band application. Band width was 10 inches (25 cm) centered over the crop row. Lima bean was irrigated with solid set sprinklers as needed to maintain adequate soil moisture for growth. All the 30-inch-spaced rows were cultivated once both years (40 d after planting in 1997 and 21 d after planting in 1998). The delay in cultivation in 1997 was due to prolonged wet weather. Weedy check plots were not included in the study as it was not feasible due to large plot size.

Weed counts were made at five randomly chosen areas using a quadrat of 2.8 ft² (0.25 m²) before lima bean harvest. The quadrat was laid perpendicular to the lima bean rows and all the weeds within the quadrats were counted.

At harvest, a 39-ft (12-m) long area (from three random locations) from each of the center two 30-inch rows and four 15-inch rows was hand harvested for the final yield. Pods were mechanically threshed and bean weight per plot recorded. In addition, a 21-oz (600-g) threshed bean sample was passed through a sieve with 0.37-inch (9.4-mm) diameter holes, and weight of beans that were retained and those that fell through the sieve were recorded separately. Weight of plump beans that stayed on the sieve is a measure of marketable beans. Percent marketable beans [(weight of beans retained on sieve/21 oz) × 100] and percent marketable yield [(yield/100) × percent marketable beans] were calculated based on weight of plump beans that were retained on the sieve.

Additionally, entire plots were harvested by a commercial combine and

yields were recorded. In 1998, only two replications were machine harvested for final yield due to inclement weather. However, all four replications were hand harvested for yield in 1998. As a measure of harvest recovery, number of pods left on plants by pod stripper and weight of beans left on ground in 66-ft² (6-m²) area at three locations were determined. Trash from a 7-oz (200-g) bean sample was separated, weight recorded, and percent trash determined.

Carpetweed (*Mollugo verticillata* L.), ivy morningglory [*Ipomea hederacea* (L.) Jacq.], common purslane (*Portulaca oleracea* L.), and fall panicum (*Panicum dichotomiflorum* Michx.) were the dominant weeds in 1997 whereas goosegrass (*Eleusine indica* L.), fall panicum, and lambsquarters (*Chenopodium album* L.) were dominant weeds in 1998.

At both locations, experimental design was a randomized complete block. There were four replications in 1997 and three replications in 1998. All data were subjected to analysis of variance and treatment means were separated by LSD at the $P = 0.05$.

Results and discussion

Due to significant year × treatment interactions, all data are presented by years.

WEED DENSITY. Weed numbers were greater in 1997 compared to 1998 (Table 1). However, no differences were noted in weed counts between treatments regardless of row spacing, herbicide rate, or application method both years.

LIMA BEAN YIELD (HAND HARVEST). Except for marketable yield in 1997, treatments did not differ in yield related measurements such as total yield and percent marketable beans (Table 2). Marketable yield was highest from rows that were 15 inches (38 cm) apart regardless of herbicide rate and was different from the rest of the treatments in 1997 only. Marketable yield was improved by 28% in 15-inch rows with either herbicide rates compared to 30-inch (76-cm) rows.

Lima bean yield from machine harvest was lower than the yield from hand harvest in both years (Table 3). Reduction can be attributed to harvest losses associated with machine harvest. Though there was no significant difference, increase in total yield from hand-harvested 15-inch rows compared to 30-inch rows was more pronounced

Table 2. Hand-harvested lima bean yield and marketable yield as influenced by weed control treatments in 1997 and 1998.

Row spacing [inches (cm)]	Treatment ^x	1997			1998		
		Total yield (lb/acre ^w)	Marketable beans ^y (%)	Marketable yield (lb/acre)	Total yield (lb/acre)	Marketable beans (%)	Marketable yield (lb/acre)
30 (76)	1× broadcast	2384	62	1478	3222	67	2158
15 (38)	1× broadcast	3059	67	2049	4074	74	3015
30 (76)	0.5× broadcast	2300	62	1426	3694	68	2512
15 (38)	0.5× broadcast	2925	68	1989	3887	71	2761
30 (76)	1× band	2369	64	1516	3530	69	2436
30 (76)	0.5× band	2425	63	1528	3088	64	1976
LSD _(0.05)		NS	NS	466	NS	NS	NS

^xHerbicide applications comprised of 1× or 0.5× rates of metolachlor plus imazethapyr preemergence. The 1× rate applied broadcast spray or in a 10-inch (25-cm) band was 1.34 lb/acre (1.5 kg·ha⁻¹) metolachlor plus 0.045 lb/acre (0.05 kg·ha⁻¹) imazethapyr. Only 30-inch-spaced rows were cultivated once, both years.

^yA 21-oz (600-g) threshed bean sample was passed through a sieve with 0.37-inch (9.4-mm) diameter holes, and weight of beans that were retained and those that fell through the sieve were recorded separately. Percent marketable beans were calculated by using the formula, (weight of beans retained on the sieve/21-oz) × 100.

^wMarketable yield = total yield × percent marketable beans.

^w1 lb/acre = 1.12 kg·ha⁻¹

Table 3. Machine-harvested lima bean yield as influenced by row spacing, herbicide rate, and method of application in 1997 and 1998.

Row spacing [inches (cm)]	Treatment ^x	Lima bean yield	
		1997 lb/acre ^y	1998 lb/acre
30 (76)	1× broadcast	1867	2214
15 (38)	1× broadcast	1815	2304
30 (76)	0.5× broadcast	1710	2365
15 (38)	0.5× broadcast	1991	2320
30 (76)	1× band	1621	2481
30 (76)	0.5× band	2291	2190
LSD _(0.05)		529	NS

^xHerbicide applications comprised of 1× or 0.5× rates of metolachlor plus imazethapyr preemergence. The 1× rate applied broadcast spray or in a 10-inch (25-cm) band was 1.34 lb/acre (1.5 kg·ha⁻¹) metolachlor plus 0.045 lb/acre (0.05 kg·ha⁻¹) imazethapyr. Only 30-inch-spaced rows were cultivated once, both years.

^y1 lb/acre = 1.12 kg·ha⁻¹.

than yield from machine harvest in both years. This may have been due to higher yield losses in 15-inch rows compared to 30-inch rows with machine-harvest. Except for yield from 30-inch rows where 0.5× rate of herbicides were banded in 1997, no differences were recorded in yield between any of the treatments both years. The reason for the increase in yield in 1997 when 0.5× rate of herbicides were banded in 15-inch rows was not clear.

HARVEST RECOVERY EVALUATIONS.

Number of pods left on lima bean plants after harvest and trash weight in the harvested samples were similar for all treatments both years (Table 4). Weight of beans lost per unit area was greater when 1× herbicide rate was applied

Table 4. Harvest efficiency^z of lima bean as affected by row spacing, herbicide rate, and method of herbicide application in 1997 and 1998.

Row spacing [inches (cm)]	Treatment ^x	1997			1998		
		Unstripped pods on plants (pods/ft ^{2w})	Wt of lost beans ^y (oz/ft ^{2v})	Trash wt (%)	Unstripped pods on plants (pods/ft ^{2w})	Wt of lost beans (oz/ft ^{2v})	Trash wt (%)
30 (76)	1× broadcast	0.4	0.04	4	2	0.3	20
15 (38)	1× broadcast	1	0.08	5	4	0.5	25
30 (76)	0.5× broadcast	0.6	0.05	4	2	0.3	15
15 (38)	0.5× broadcast	1	0.06	7	4	0.5	26
30 (76)	1× band	0.5	0.04	4	1	0.2	27
30 (76)	0.5× band	0.4	0.04	5	2	0.3	23
LSD (0.05)		NS	0.03	NS	NS	NS	NS

^zHarvest efficacy was measured by number of pods left on plants after harvest, weight of loose beans left on ground plus weight of beans from unthreshed pods left on ground after lima bean harvest, and weight of trash from 7-oz (200-g) of bean sample expressed in %. Trash weight was higher in 1998 is due to inclusion of unmarketable beans in the trash.

^yWeight of beans lost = weight of loose beans left on ground plus weight of beans from unthreshed pods left on ground after lima bean harvest.

^xHerbicide applications comprised of 1× or 0.5× rates of metolachlor plus imazethapyr preemergence. The 1× rate applied broadcast spray or in a 10-inch (25-cm) band was 1.34 lb/acre (1.5 kg·ha⁻¹) metolachlor plus 0.045 lb/acre (0.05 kg·ha⁻¹) imazethapyr. Only 30-inch-spaced rows were cultivated once, both years.

^w1 pod/ft² = 11 pods/m².

^v1 oz/ft² = 305 g·m⁻².

broadcast on 15-inch row plots in 1997, the reason for which is not apparent. However, no differences were observed between treatments in 1998.

Results from these studies indicate that reduced rates of metolachlor plus imazethapyr as either broadcast or band applications (PRE) resulted in weed control, lima bean yields, and harvest recovery equivalent to full rates regardless of row spacings. Our findings are in agreement with similar soybean research that reported no differences in weed control and yield between full and reduced rates of herbicides and narrow [10-inch (25-cm) and 15-inch rows] and wide (30-inch) row spacings (Forcella et al., 1992; Muyonga et al., 1996).

The inconsistency of the effect of row spacing on economic (marketable) yield as noted in this study is similar to the results reported by Larson and Peng Fi-Li (1948). Larson and Peng Fi-Li (1948) showed that depending on location in Pennsylvania, lima bean in 20-inch (51-cm) rows produced more, the same, or less economic yield compared to 30-inch rows. Sirait et al. (1994) suggested that higher economic yield in 15-inch rows which had high plant populations compared to 30-inch rows was associated with greater plant weights per plot. In this study, insignificant yield increase noted in 15-inch rows may have been due to higher plant population with 15-inch rows compared to 30-inch rows.

Though not significant, harvest losses were higher in 15-inch rows than in 30-inch rows in both years. For instance, weight of beans lost on ground were 44% to 67% higher in 15-inch rows than that recorded in 30-inch rows in 1998. This translates to a bean loss of 370 to 507 lb/acre (415 to 568 kg·ha⁻¹) worth \$358 to \$492/acre (\$145 to \$199/ha). This is a substantial yield and monetary loss to the grower.

Reduced herbicide rates provided consistent weed control similar to the 1× rate in this study without a cultivation in 15-inch rows. However, some weeds escape, even at full rates of herbicides, requiring a follow up cultivation. It appears that there is no clear benefit to planting lima bean in narrow rows. In addition to no yield advantage, harvest losses as discussed above are higher with 15-inch rows compared to 30-inch rows.

Also, conventional harvester configuration and setup may not be well suited to harvest lima bean grown in narrow rows. Future research should identify if potential other benefits exist before advocating narrow row spacing in lima bean.

Based on the results of this research, planting lima bean in traditional wide rows and switching from chemical-intensive systems to low-use rate systems complemented with mechanical weed management appears to be a viable alternative. The use of reduced herbicide rates can fit with intensive-management, integrated-production systems. This information helps in developing tactics for integrated weed management systems in lima bean.

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