HortScience 60(3):267–272. 2025. https://doi.org/10.21273/HORTSCI18254-24

Crop and Weed Management Practices of Snap Bean (*Phaseolus vulgaris*) Production Fields in the United States

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Keywords. field records, herbicides, processing snap bean, production regions

Abstract. **Agronomic and weed management practices employed by growers in the production of snap bean (*Phaseolus vulgaris*) for the processing industry are poorly characterized. To address this knowledge gap, records of agronomic and weed management practices from 358 snap bean fields were obtained from collaborating processors. These fields encompassed three production regions in the United States: the Northwest (NW), Midwest (MW), and Northeast (NE). The obtained records were formatted to be more suitable for presentation or analysis. Forty cultivars were used across all three regions, primarily of green round podded type (~90% of all fields). However, it was common for only relatively few cultivars to be widespread in each region. Seeding rates were substantially higher (by more than 100,000 plants/ha on average) in the NW region. Crop row widths were also narrower in the NW region compared with other regions. Planting and harvest occurred across a wide range of dates in all three production regions, with the NW having a delay of ~10 days. The most common crop in rotation with snap bean was usually some type of corn, although the NW region had more variability in crop rotation. Spring tillage and irrigation were commonly used practices across all regions. Weed management was dominated by the use of interrow cultivation and a narrow spectrum of preemergence and postemergence herbicides. However, interrow cultivation was not used as much in the NW compared with the other two regions. Snap bean grown in the NW production region showed a departure in agronomic and weed management practices compared with the MW and NE production regions.**

Snap bean represents various cultivars of common bean (*Phaseolus vulgaris* L.). Although most common bean is grown for seed, snap bean cultivars are grown for their young and unripe fruits (pods). More than 80% of snap bean is grown for processing, primarily for canning, with the remainder grown for the fresh market (Davis et al. 2023). Approximately 65,000 ha of snap bean are grown in the United States with a farmgate value of $360 million [US Department of Agriculture–National Agricultural Research Service (USDA-NASS) 2024]. Current production reflects a 30% decrease since 2016 (USDA-NASS 2024). The sharp decline in production is the result of greater imports of snap bean products and a change in consumer preference toward fresh and frozen, rather than canned, products (Davis et al. 2023). The extent to which these, and future, changes in the market influence US snap bean production remains to be seen.

Recommendations for snap bean production can be found in extension bulletins from public institutions, such as the Mid-Atlantic Commercial Vegetable Production Recommendations (Wyenandt et al. 2024). Such guides address multiple crop production issues, such as variety selection, planting date, seeding rate, fertilization, and proper irrigation. Also included are recommendations for the management of pests, including weeds, which threaten the economic sustainability of the crop (Boyhan et al. 2013; Delahaut and Newenhouse 1997; Kaiser and Ernst 2017; Peachey 2019; Rutledge 1995). If left uncontrolled, weeds can cause up to 80% yield loss in snap beans (Qasem 1995; Odero and Wright 2018). Weed management practices in commercial snap bean production include mechanical and chemical controls (Peachey 2019). Mechanical weed control relies on tillage either before, or after planting snap bean but before emergence, as well as interrow cultivation after its emergence. Chemical weed control relies on the use of synthetic herbicides applied either preemergence (PRE) or postemergence (POST). The use of recommended practices and insight on the types and frequency of crop and weed management tactics used in snap bean production is lacking. Therefore, the objective of this work was to characterize crop and weed management practices employed by the growers across three distinct production regions of the United States.

Materials and Methods

Between 2019 and 2023, collaborating vegetable processors provided lists of fields scheduled for harvest from which a random sample of fields was drawn and field scouted for present weed species. Field scouting was conducted across a broad window of snap bean harvest from June to October. Ultimately, 358 processing snap bean fields across three US production regions were field scouted. The results of this field scouting survey can be found in Pavlovic et al. (2024).

This research was based on field records of these 358 snap bean fields, which were provided by the collaborating processors. They provided geospatial location of all fields and the agronomic and weed management practices used throughout the growing season. These fields were spread across three US production regions: Oregon and Washington in the Northwest (NW); Illinois, Iowa, Minnesota, and Wisconsin in the Midwest (MW); and Delaware, Maryland, New York, and Pennsylvania in the Northeast (NE) (Supplemental Table 1).

The provided field records on agronomic and weed management practices were formatted to be more suitable for presentation or analysis. Agronomic practices presented are snap bean variety, seeding rate and row width, planting and harvest period (hereafter, "early" corresponds to the first through the 10th day of the month, "mid" corresponds to the 11th through 20th day of the month, and "late" corresponds to 21st to last day of the month), preceding crop, preplant tillage type, and use of irrigation. Weed management practices included the use of hand weeding (manual human labor), interrow cultivation (tractor implements), herbicide application type (no herbicide application, PRE or POST herbicides only, and both PRE and POST herbicides), and PRE and POST active ingredient, and their corresponding modes of action (MoA).

The data were not normally distributed or homoscedastic; therefore, a nonparametric analysis was employed. The Wilcoxon–Mann–Whitney U test was used to compare the three surveyed regions for planting date and harvest date (Fay and Proschan 2010; Mann and Whitney 1947). Seeding rates were only compared between the NW and MW regions due to the absence of data for the NE region. For analysis, the planting and harvest dates were converted to an ordinal scale in the form of Julian day. Fisher's exact test was used to determine whether there was a significant relationship between herbicide application type and interrow cultivation and between row width and row cultivation in NW region where different row widths were used (Agresti 1992). These relationships were determined by testing the following alternate hypotheses: 1) interrow cultivation was more frequent in fields where there was no herbicide application or had PRE or POST only herbicide application compared with fields that had both PRE and POST herbicide applications; 2) in the NW region interrow cultivation was more frequent in fields with wider rows (76.2 cm) compared with fields with narrower rows (<76.2 cm). All statistical analyses were considered significant at P values < 0.05 and were conducted in the R statistical software (R Core Team 2023, version 4.3.2).

Results and Discussion

Agronomic practices. Snap bean cultivars were primarily green round podded types (89.4%), with the remainder being of green flat podded types (8.9%) and yellow (wax) round podded types (1.7%) (data not shown). Cultivar types observed in the field records all have mostly similar pod lengths, sieve sizes, and days (55 to 60) to harvest (Rutledge 1995; Wyenandt et al. 2024). 'Venture' was the most common cultivar used across all regions (Fig. 1A). Three additional snap bean cultivars were used in two or more regions—namely, Pismo, BA1001, and Tapia. The other 36 cultivars appeared only in one region. This information indicates that it was common for only relatively few cultivars to be widespread in each processing region, with some cultivars grown under a wide range of environmental conditions.

Planting and harvest occurred across a wide range of dates in all three production regions (Fig. 1B). The earliest plantings occurred in mid-April. The latest plantings occurred in early August. The range of planting dates is consistent with what was recommended by Wyenandt et al. (2024). Harvest dates ranged from late June to early October (data not shown). The period between planting and harvest was ∼10 d later in the NW compared with the other two regions (P = 0.014 for comparison with MW; P = 0.004 for comparison with NE). There is a possibility that this delay in harvest is, to a certain extent, attributable to cultivars grown in NW. However, Boydston and Williams (2017) planted cultivar Sahara in Illinois (MW) and Washington (NW) and reported that harvest was delayed by more than a week in Washington compared with Illinois. Wyenandt et al. (2024) also noted that different cultivars grown in a similar environment generally take similar amount of time to reach maturity. This is an indication that the environment has a greater effect on the time of snap bean maturity than the genetics of the variety. The delay in maturity in NW is primarily attributable to colder nights (Peachey E, personal communication).

In field records a variety of crops preceding snap bean were observed (Fig. 1C). However, in most fields some type of corn (field corn, sweet corn, seed corn, or popcorn) was the most common crop preceding snap bean in previous year. In the MW snap bean as a preceding crop was common (∼20% of fields) and reflects a snap bean double-crop system within the same year. Fields in the NW had the most diversity of preceding crops, including forage crops. Except for double-crop situations, preceding crops reflected recommendations to avoid snap bean pathogens (Bourne et al. 1997).

Seeding rates varied by region. In the NW, seeding rates were on average 100,000 seeds/ha greater than the MW ($P < 0.01$) (Fig. 2). The increased seeding rate in NW was in part due to narrower crop rows in the region. Most fields (77.5%) in NW had rows narrower than 76.2 cm (Fig. 3A). In the other two regions, most row spacings were 76.2 cm. Snap

Received for publication 21 Oct 2024. Accepted for publication 11 Dec 2024.
Published online 31 Jan 2025.
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This research was supported by US Department of Agriculture–Agricultural Research Service Research Project No. 5012-12220-010-000D. This paper is part of a master's thesis submitted by Pavle Pavlovic in fulfilling a degree requirement. We thank the students and employees of the Marty Williams Lab who assisted with data collection, including Nicholas Hausman, Christopher Landau, Jim Moody, Ana Saballos, and Yudai Takenaka. We also deeply appreciate the vegetable processors and farmers who participated in this research.
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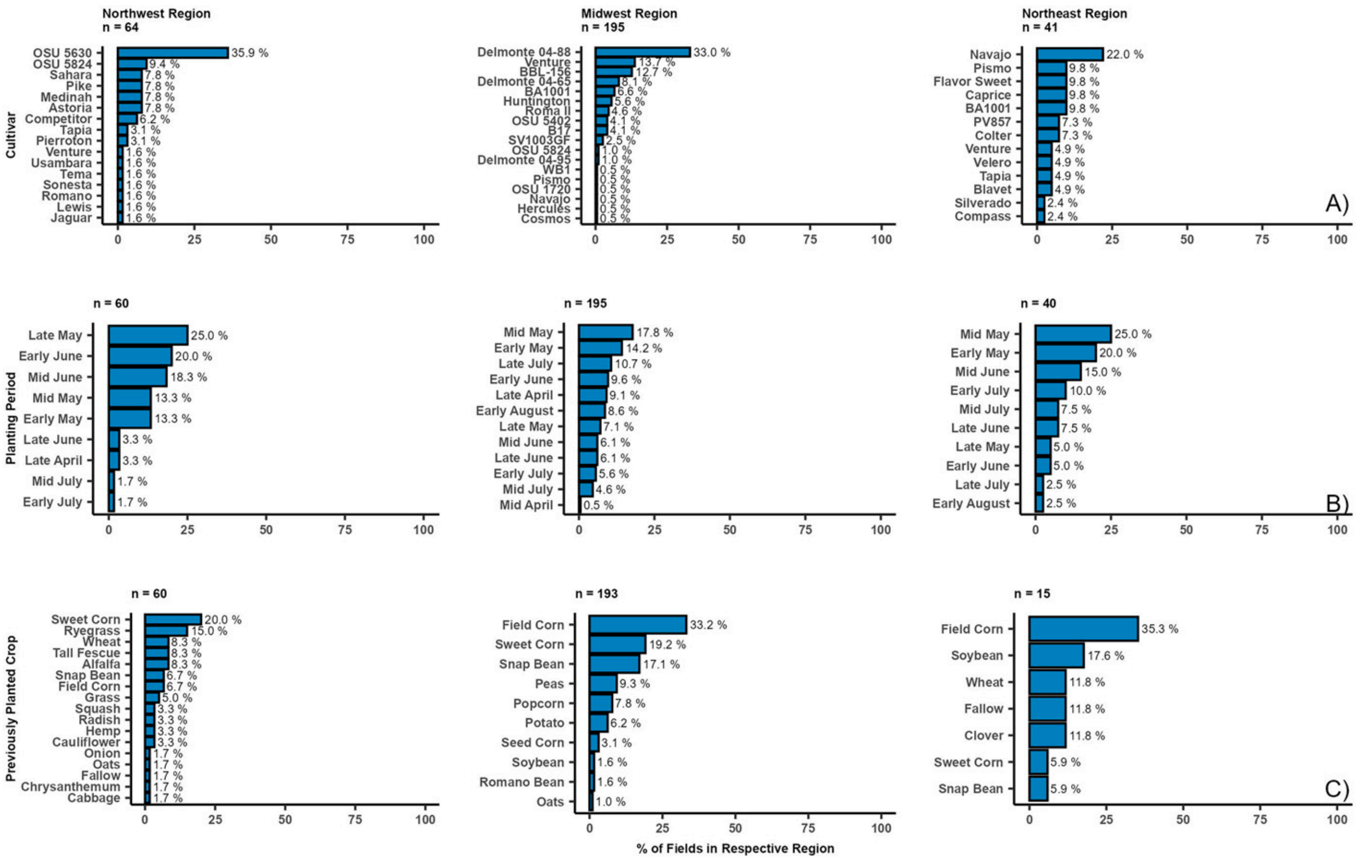

Fig. 1. Bar chart illustrations of (**A**) variety, (**B**) planting period, and (**C**) preceding crop by region, with the accompanying number of observations.

bean being rotated with a greater variety of crops in NW may have led to the use of planting equipment more customized for vegetables and cereals, which explains narrower row spacings. In the MW and NE regions, planters for corn were probably used, which explains the 76.2-cm spacing typically used for corn. Trials related to the effect of row width planting on weed population were conducted by Teasdale and Frank (1982, 1983). The results of these trials indicate that in the narrower rows, the snap bean closed the canopy sooner compared with snap bean planted in wider rows, resulting in better competition with weeds. However, the researchers also noted that snap bean

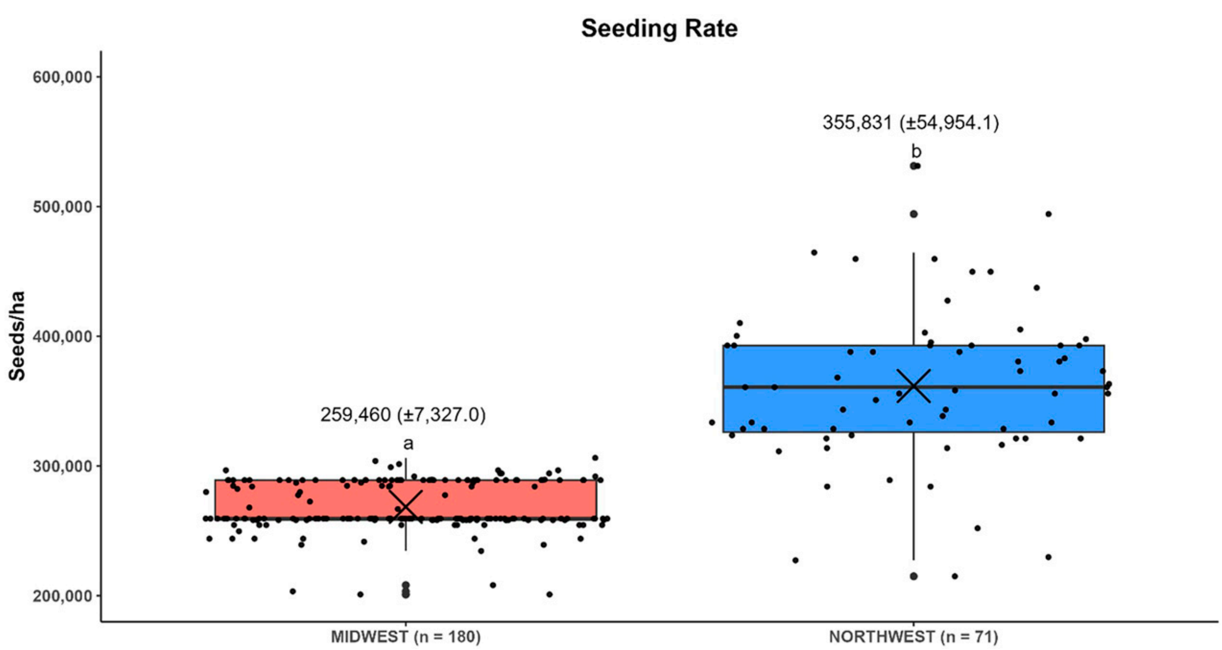

Fig. 2. Box-and-whisker plot of seeding rate by region. Values above the box-and-whisker plots represent the median values and median absolute deviation in parentheses with letters denoting significant differences based on the Wilcoxon–Mann–Whitney *U* test. Cross symbol denotes the mean value of each regional subset. *Only the Northwest and Midwest regions were compared because data were missing for the Northeast region.

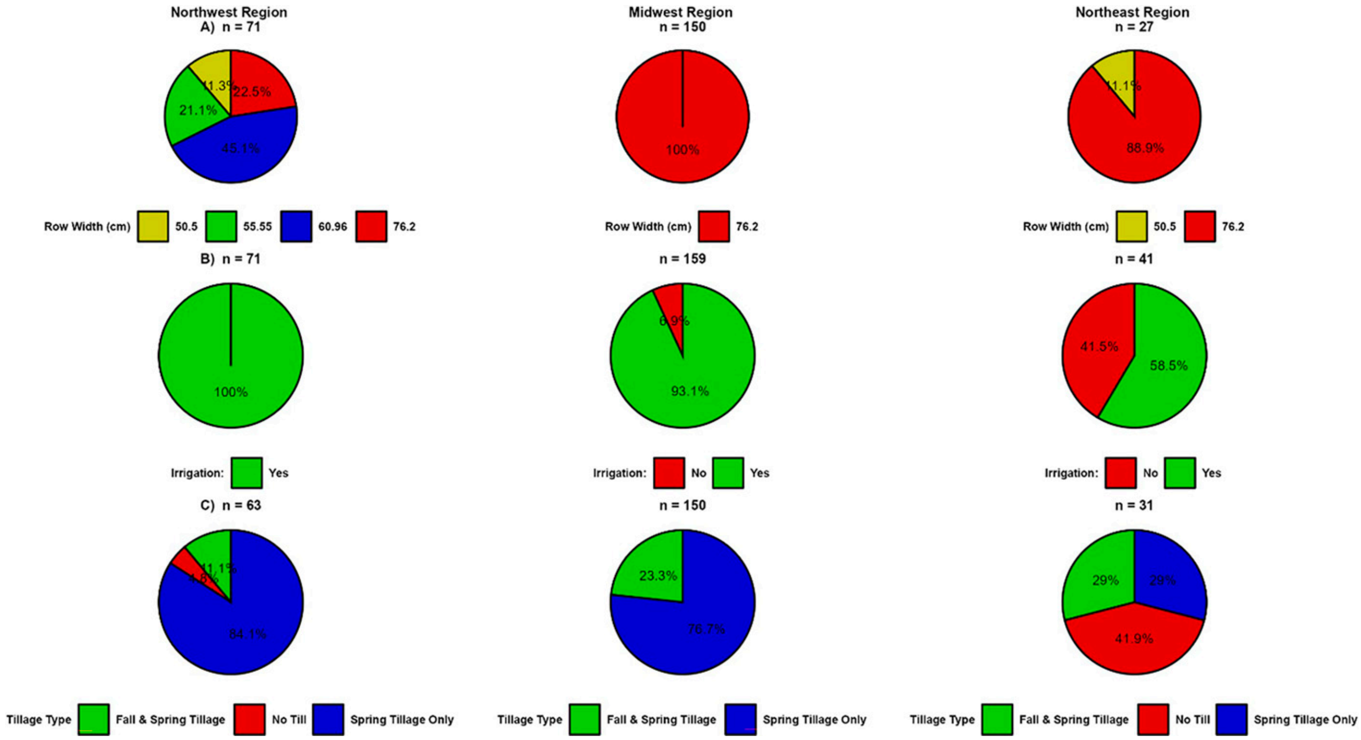

Fig. 3. Pie chart illustrations of (**A**) row width, (**B**) irrigation, (**C**) tillage type by region, with the accompanying number of observations.

planted in narrower rows can limit the use of interrow cultivation, resulting in mechanical crop injury.

Irrigation was used in most snap bean fields, with the exception of the NE, where 41.5% of fields grown under rainfed conditions (Fig. 3B). This demonstrates that irrigation had an almost ubiquitous presence in production, as previous studies have demonstrated that even temporary drought conditions result in substantial yield reduction, especially during flowering and pod sizing growth stages (Beshir et al. 2016). Also, sufficient water supply, especially during flowering and pod fill, is necessary to maximize snap bean yield (Boyhan et al. 2013; Delahaut and Newenhouse 1997; Wyenandt et al. 2024).

Weed management practices. Spring tillage was practiced on 94.2% of snap bean fields (Fig. 3C). Preplant tillage is a common practice in snap bean for weed control and optimal seed-to-soil contact (Peachey 2019). Fall tillage (before snap bean planting) was generally avoided in all the regions, and when used, it was always followed by spring tillage. The possible reason for no fall tillage was to let the weed seeds remain on the soil surface where they are exposed to cold temperatures, wetting, and predation, which results in a decrease in potential weed population in the spring (Peachey 2019). In Oregon, one of the reasons for limited fall tillage is also to avoid soil erosion because excessive precipitation during this period of the year can exacerbate this issue (Peachey E, personal communication). Usually, one or two spring tillage operations were used on the fields (75.2%), although there were fields with additional tillage operations (data not shown). Spring tillage would provide early season weed control by applying stale and false seedbed techniques (Peachey 2019).

Other forms of mechanical weed control that were used in snap bean fields were hand weeding and row cultivation. Hand weeding was used on up to 16.7% of the fields in the NW (Fig. 4A). The rare use of hand weeding in snap bean production was probably due to the associated high costs of labor (Peachey 2019). Interrow cultivation was a more common form of mechanical weed control and was used in 60.7% of fields. However, the frequency of interrow cultivation varied by region; with interrow cultivation ranging from 28.6% and 75.6% for the NW and MW, respectively (Fig. 4B). As noted by Teasdale and Frank (1982, 1983), snap bean planted in narrower rows limits the use of interrow cultivation, due to risk of mechanical crop injury, possibly explaining its low use rate in NW region. Other possible reason might also be a lack of interrow cultivation equipment adjusted for narrower rows.

Herbicides are used widely in snap bean production, as evidenced by their use on 86.8% of fields (Fig. 4C). This was to be expected because herbicides are considered the most cost-effective weed control tactic in snap bean production (Peachey 2019). Most fields in the NE and NW received a combination of at least one PRE and POST herbicide application, whereas PRE only was the most common application type in the MW (50.5%). PRE applications followed by POST applications suggest weed escapees from PRE necessitated additional intervention.

Use of interrow cultivation was comparable in fields where there was no herbicide application, or had PRE or POST only herbicide application, to fields that had both PRE and POST herbicide application in the MW ($n = 175$, Fisher's exact $P = 0.73$) and the NW ($n = 53$, Fisher's exact $P = 0.08$) both. In addition, in the NW, interrow cultivation was comparable in wider rows and narrower rows ($n = 63$, Fisher's exact $P = 0.43$). These results show that use of interrow cultivation wasn't affected by herbicide application or row width. Interrow cultivation may have been employed in the weediest fields.

The diversity of effective herbicides is limited in snap bean (Peachey 2019). Overuse of a single herbicide active ingredient or MoA favors evolution of herbicide resistance. We observed a maximum of five MoAs used in fields; however, often fewer MoAs were employed (data not shown). Overall, two or three MoAs were employed in 53.2% of fields. One exception was the NW, where 61.9% of fields received three or four MoAs. These results indicated higher diversity in MoAs in the NW compared with the other two regions.

Very long chain fatty acid (VLCFA) inhibitors were the most common herbicides applied in PRE across all regions (Fig. 5A). Acetolactate synthase (ALS) inhibitors, microtubule assembly inhibitors, and protoporphyrinogen oxidase (PPO) inhibitors were also commonly applied PRE. ALS inhibitors were more common only in the MW and NW, while microtubule assembly inhibitors and PPO inhibitors were more common in the NE and MW, respectively. The most dominant VLCFA inhibiting active ingredient was *S*-metolachlor, followed by S-ethyl dipropylthiocarbamate (EPTC), except in NE where EPTC was a more dominant active ingredient

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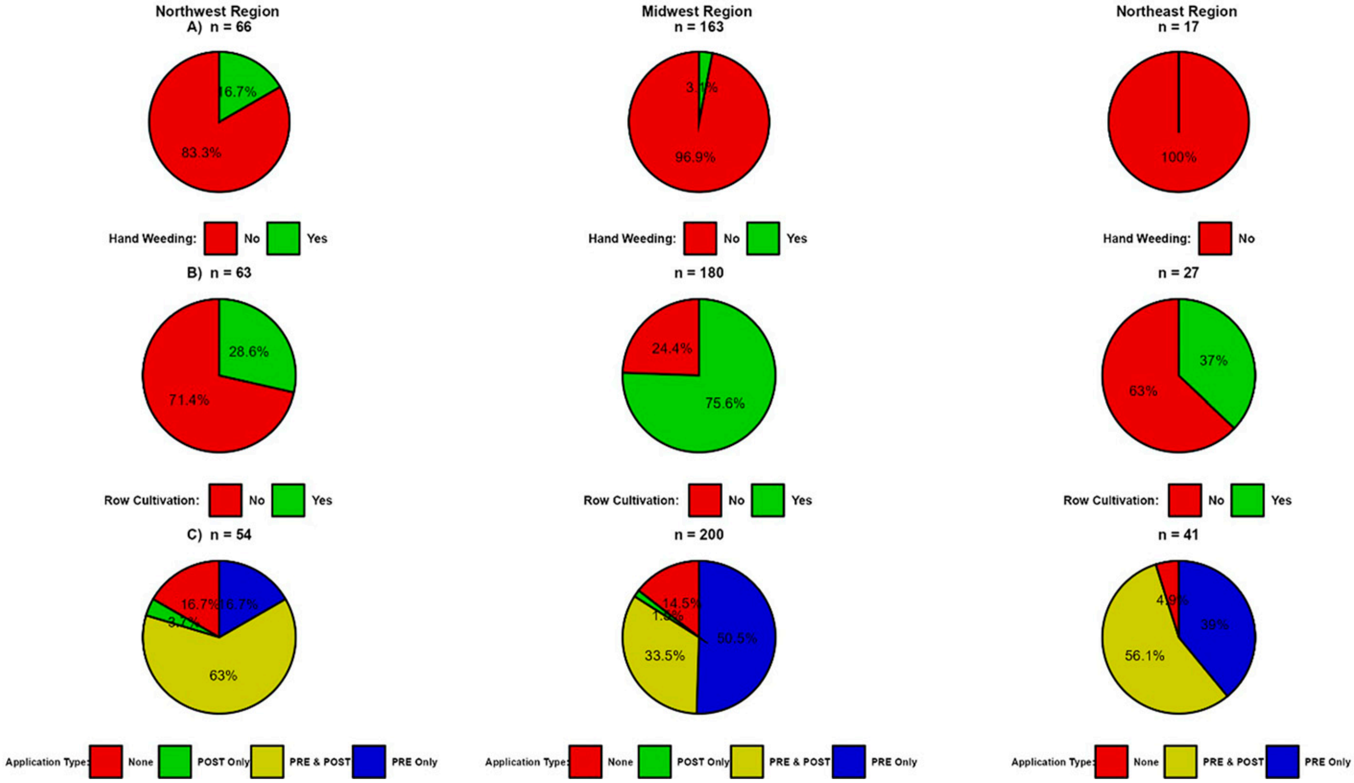

Fig. 4. Pie chart illustrations of (**A**) hand weeding, (**B**) row cultivation, and (**C**) herbicide application type by region, with the accompanying number of observations.

(Fig. 5B). The most frequently used MoA in POST applications in every region was Photosystem II (PSII) inhibitors (Fig. 5C). Other common MoAs applied POST were ALS inhibitors and PPO inhibitors. The most common PSII inhibiting active ingredient was bentazon, which was usually mixed with ALS inhibiting active ingredient imazamox, as crop safety from imazamox injury is increased when mixed with bentazon (Fig. 5D) (BASF Corporation 2021). The simplicity of weed management in snap bean favors the evolution of

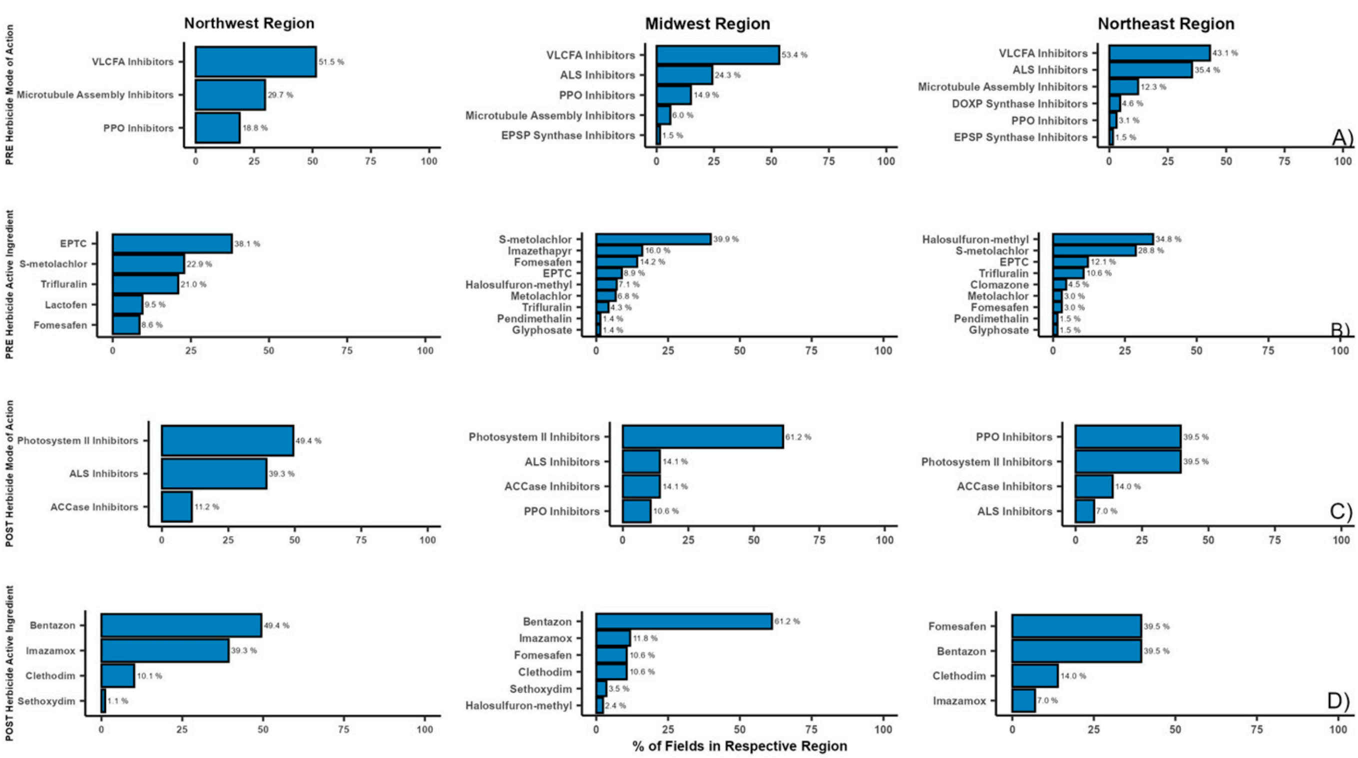

Fig. 5. Bar chart illustrations of (**A**) preemergence (PRE) herbicide modes of action, (**B**) PRE herbicide active ingredients, (**C**) postemergence (POST) herbicide modes of action, and (**D**) POST herbicide active ingredients by region. ACCase = acetyl-CoA carboxylase; ALS = acetolactate synthase; EPTC = S-ethyl dipropylthiocarbamate; ESPS = 5-enolpyruvylshikimate-3-phosphate; PPO = protoporphyrinogen oxidase; VLCFA = very long chain fatty.

herbicide resistance; however, selection pressure for resistance also depends on the complexity of weed management systems employed in rotation crops. In addition, most of the listed herbicides have been registered in snap bean production for decades, while new registrations are rare because few new herbicides are being developed, especially for specialty crops (Fennimore and Doohan 2008).

Conclusion

Results of this survey are the first of their kind in snap bean. Common practices follow recommended guidelines, such as the use of irrigation, avoiding fall tillage that buries weed seeds, and spring tillage that ensures a proper seedbed. Other results provide insight into broader characteristics of snap bean production. For example, some varieties grown in snap bean production are region specific, whereas other varieties are grown in multiple regions. Green-podded types dominate. It has also been observed that snap bean in NW matures later compared with the other two regions. The NW also displayed a more diverse production of crops in rotation with snap bean. Regarding weed control, most fields are cultivated and rely on herbicides. Interrow cultivation was unaffected by the use of other weed management practices. While herbicides were used extensively across all regions, the lack of diversity in MoA and active ingredients is a concern for herbicide resistance management. Lack of herbicide diversity is the result of limited herbicides registered on the crop. The information presented here could prove useful to growers, extension, industry, and university personnel for improving the long-term sustainability of US processing snap bean production.

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