A Time-Efficient Scooping Method to Prepare Cover Crop Seed for Cone Planters

Eric B. Brennan*

ABSTRACT

Cone planters (CP) uniformly distribute seed over research plots; however, preparing seed for CP by weighing is time-consuming. This study evaluated (i) the effect of seed preparation method (scooping with a calibrated cup vs. weighing) on population density of monoculture cover crops planted with a CP, (ii) time required for scooping vs. weighing, and (iii) the effect of scooping on segregation of pre-made cover crop mixtures. Monocultures included mustard [*Brassica juncea* (L.) Czern.], rye (*Secale cereale* L.), common vetch (*Vicia sativa* L.), and faba bean (*Vicia faba* L.) planted at 1×, 2×, and 4× seeding rates; 1× rates in pure live seed m^{-2} were 24 (faba bean), 43 (common vetch), 291 (rye), and 310 (mustard). Mixtures contained rye, oat (*Avena sativa* L.), barley (*Hordeum vulgare* L.), faba bean, common vetch, or pea (*Pisum sativum* L.), and by weight included: Mix 1 (10% rye, 90% faba bean), Mix 2 (10% oat, 90% faba bean), Mix 3 (10% barley, 90% faba bean), Mix 4 (10% common vetch, 90% rye), and Mix 5 (10% rye, 25% pea, 30% common vetch, 35% faba bean). Seed preparation method did not affect the population densities of the monocultures. Preparing seed packets was at least two times more time-consuming with the weighing than scooping method. Calibrating cups to scoop within 1% of the desired seed packet weight was not difficult. However, segregation occurred while scooping some mixtures from a bucket whereby smaller-seeded components increased with scooping depth. Simple methods to detect seed segregation in mixtures are discussed.

Cone planters were developed more than 50 yr ago to evenly distribute seed or other granular material in one or more lines over small research plots (Berg, 1958; Beard and Johnson, 1960; Niemczyk and Prins, 1963; Oyjord, 1963; Mills, 1969). Several types of hand-pushed and tractor-mounted CP have been described and both types are commercially available (Dewey et al., 1970; Schmid, 1971; Marshall, 1972; Wiseman et al., 1972; Peacock et al., 1973; Barker et al., 1976; Cobb et al., 1977; Vogel, 1978; Dewey et al., 1979; Knapp and Trenchard, 1979; Engel et al., 2003). Rotating cones on these planters distribute the seed over a plot length that is determined with an adjustable-speed drive. The seeding rate is determined by the weight of seed that is added to the cone for a single rotation over the specified plot length. The self-cleaning feature is a major advantage of CP and allows researchers to efficiently change seed variety and seeding rate by hundreds of kg ha^{-1} in contiguous plots that are planted in a single pass without stopping the planter. In addition, a seed mixture that would typically require two hoppers to prevent segregation by seed size can be planted from the same cone in a single pass with a CP. These features make the CP an indispensable tool to reduce planting time and field space required for trials with multiple plant varieties and seeding rates.

Despite the benefits of CP, preparing individual seed packets for CP is labor-intensive and often exceeds by severalfold the time required for planting. Seed preparation is especially time-consuming when multiple-cone planters are used to plant relatively large plots with several passes (Boyd et al., 2009; Brennan et al., 2009), and where the cones need to be reloaded more than once because the plot length exceeds the cone's seeding capacity with a single revolution. For example, 576 packets of seed are needed annually to plant the cover cropping phase in 24 plots in a 0.76 ha area of a long-term trial on the effects of cover crop variety and seeding rate on organic vegetable production in Salinas, CA. Each of the plots in this trial that receive the annual cover crop is 12 m wide by 20 m long and is planted with three passes with a 4.6-m wide commercial grain drill with four cones that each distribute seed into seven rows spaced 15 cm apart. Two cone revolutions are needed for each pass over each plot to achieve the highest seeding rate (420 kg ha^{-1}) treatment of a legume-rye cover crop mixture. Seed preparation for cover crop mixtures is considerably more time-consuming than for monoculture cover crops if the mixture components are added separately to each packet of seed to ensure that each packet includes the same proportions of the mixture components.

Weighing the seed for each packet to be loaded into each cone is theoretically the most precise method to achieve the desired seeding rate for a given plot area. Previous studies described tools to reduce the time required for preparing seed for CP, including a modified Boerner divider that splits a sample evenly (Clark and Fehr, 1973) and a powder measure metering device that is typically used to dispense gun powder for hand-made ammunition (McGinnies, 1961). Boerner dividers are extremely precise tools to divide seed (i.e., ± 1% error for a 1000-g sample); however, they are expensive (>U.S. $1500). Furthermore, powder measures are only useful for small quantities of small-sized seed because their discharge capacity is usually less than 10 cm^{-3}. An alternative, simple,

Eric B. Brennan, USDA-ARS, 1636 East Alisal Street, Salinas, CA 93905.
Received 23 Sept. 2010. *Corresponding author (eric.brennan@ars.usda.gov).

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Abbreviations: Cone planters, CP.

Table 1. Thousand seed weights and seeding rates in the four field experiments with monoculture cover crops.

Experiment	1000-seed weight, g†	Seeding rate, g‡			Pure live seeding rate m^{-2}§
		1×	2×	4×	
Mustard	2.4	10	20	40	310
Rye	17	60	120	240	291
Vetch	75	40	80	160	43
Faba bean	338	100	200	400	24

† 1000-seed weights of pure seed.

‡ Desired amount of seed for each packet that was loaded into each cone of the planter. Seeding rates in kg ha^{-1} can be calculated by multiplying the seed packet weight by 0.73.

§ Planting densities are only shown for the 1x rate for each experiment and assume that 90% of the pure live seed in each packet was captured by the belt on the cone and distributed evenly over seven rows in a 12.37 m^{-2} area planted by a single cone.

and inexpensive method for seed preparation that has not been evaluated involves scooping seed with a cup whose volume is calibrated to deliver the desired weight of seed for each packet. The objectives of this study were to (i) evaluate the effect of seed packet preparation method (weighing vs. scooping) on cover crop population density over a range of seeding rates of four monocultures that were planted with a CP, (ii) compare the time required for preparing seed packets by scooping vs. weighing, and (iii) determine the effect of the scooping method on the composition of pre-made cover crop mixtures.

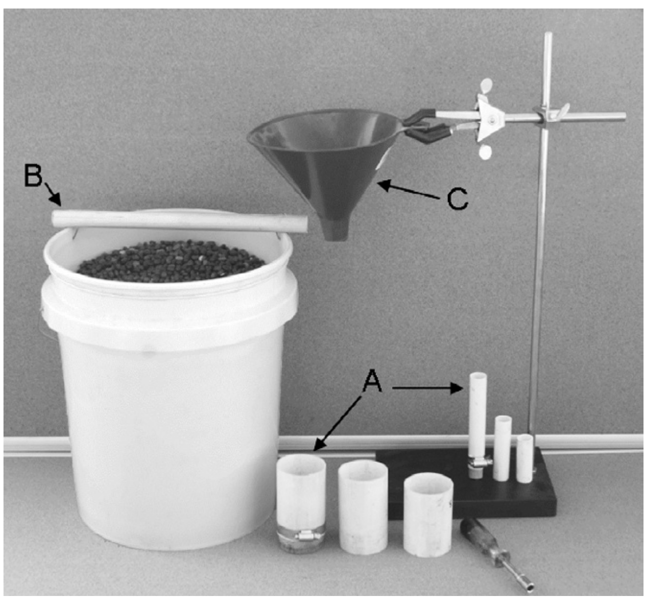

Fig. 1. Equipment used to prepare seed packets by the scooping method in the timed comparison of scooping vs. weighing. Calibrated cups (A) for scooping seed were made from polyvinyl tubing and had a wooden stopper in the bottom that was secured by a hose clamp; the wooden stopper was held in place with duct tape during the seed preparation for the field experiment. The socket-ended screwdriver was used to tighten the hose clamp around tubing where the stopper was inserted. In the timed comparison, the cup made from the larger diameter tubing (6 cm) was used to scoop faba bean and oat, and the cup from the smaller diameter tubing (2.2 cm) was used to scoop mustard. Additional tubes of various lengths are on the right of each calibrated cup. The small diameter tube (B), attached with wire to the top of the bucket, was used to scrape off excess seed from the brim of the cup before the scooped seed was transferred into a plastic seed packet via the funnel (C).

MATERIALS AND METHODS

Field Experiments with Monocultures

The field experiments occurred at the USDA-ARS certified organic research farm in Salinas, CA where the soil is a Chualar loamy sand (fine-loamy, mixed, thermic Typic Argixerol). Field preparation included discing, chiseling, and ring rolling as needed to prepare the field to the typical standard for cover crop planting in this region. The previous crop was a cover mixture of rye and faba bean. Cover crop seed was obtained from L.A. Hearne Company (King City, CA). For each of the four cover crops, a randomized complete block design with a factorial arrangement of three seeding rates (1×, 2×, 4×) and two seed preparation methods (weighing and scooping) in four replicates was used (Table 1). The electronic balance used to determine seed packet weights was accurate to 0.001 g for the mustard experiment and 0.1 g for the other experiments. The calibrated cups were made from disposable plastic pipet tips for the lowest target packet weight for mustard, and various lengths of polyvinyl chloride tubing (2.2-cm and 6-cm outer diameter) with a 4- to 5-cm-long wooden stopper inserted in the bottom to adjust the cup's volume; the wall thickness of the tubing was approximately 1 and 2 mm for the small and large tubing, respectively (Fig. 1). The wooden stopper extended beyond the bottom of the cup and was secured in place by wrapping duct tape around the stopper and cup. The cup for each target seed packet weight was calibrated by adjusting the cup volume so that the seed from a randomly selected target packet weight filled the cup to the brim. The method for filling the calibrated cup involved scooping a sample of seed from a bag and briefly and gently shaking the cup horizontally so that the seed at the brim was relatively even with the brim.

Seed weights per packet were obtained before planting to determine if variation in weight between seed preparation methods affected the plant density in the field. The cover crops were planted with a 4.6-m-wide grain drill (Model 1500, Great Plains Mfg., Salina, KS) that was modified by Kinkaid Equipment Mfg., (Haven, KS) to include four 25.4-cm diameter belt cones that each distributed seed to seven rows spaced 15 cm apart. The seed traveled through a tube that ended in a double disc opener followed by a rubber press wheel for each row. The plot length was determined by adjusting the Zero-Max adjustable-speed drive (Zero-Max Inc., Plymouth, MN) on the planter to make a full revolution in 12.37 m. Each plot was planted by a single cone. The planting depth was approximately 4 cm. The planting occurred on 2 Aug. 2010 and required approximately 1 h to plant the 24 plots of each of the four monoculture trials. The plots were sprinkle irrigated as needed to germinate the cover crops and achieve a uniform stand.

The percentage purity of the seed was determined from a sample containing approximately 2500 seed of each seed type. The percentage germination was determined for three samples of 100 pure seed for cover crop. The percentage of pure live seed (percentage purity × percentage germination) was 99% for rye and faba bean, 98% for common vetch, and 93% for mustard. Expected cover crop densities were calculated based on the amount of pure live seed in each packet, and it was assumed that 90% of the seed loaded into each cone was caught by the belt and thus evenly distributed over the plot length. Cover crop densities were determined in a 1-m section of the center three rows for each plot, and in most plots the three rows counted were immediately adjacent to each other. Cover crop densities for rye, mustard, and common vetch were determined by carefully uprooting the 1-m row sections with a trowel and counting the plants. Cover crop density counts occurred on 11 to 16 d after planting. Most plants emerged above the soil surface; however, yellow colored plants just below the soil surface were also counted as emerged. Due to the relatively low density of faba bean, uprooting was not necessary for plant counts. Cover crop plant counts in the three rows were converted to plant counts m^{-2} whereby there were six 1-m rows m^{-2}.

Time Required for Weighing Versus Scooping

Three monoculture seed types (mustard, faba bean, and oat) were used to compare the amount of time required to prepare seed packets by scooping vs. weighing. The seed packets used were resealable plastic bags that were 10 by 10 cm for mustard and 15 by 25 cm for faba bean and oat. A separate experiment was conducted for each seed type. The experimental design was a randomized complete block design with four replicates. The time required to fill five seed packets by scooping vs. weighing was recorded for each replicate of each seed type. The target quantity of seed for each packet was 10 g for mustard and 100 g for faba bean and oat. For the mustard experiment, a 2.2-cm diameter cup was calibrated to scoop 10 g of seed with a 1% error rate (i.e., 10 ± 0.1 g). For the faba bean and oat experiments, a 6-cm diameter cup was calibrated to scoop 100 ± 1 g. For the weighing method, the seed was added or removed from an electronic balance to obtain within 1% of the target weight. During scooping, the seed at the cup's brim was leveled by scraping it along a 2.2-cm tube that straddled the mouth of the bucket (Fig. 1); scraping the brim improved the accuracy of the scooping method to within 1% desired weight. A hose clamp was secured around the end of the cup with the wooden stopper to prevent the stopper from moving during scooping. A funnel attached to a support stand was used to transfer the weighed and scooped seed into the plastic packets without spillage. The timed comparisons did not include the time to open the seal on the packets, calibrate the cups, set up the electronic balance, or fill the bucket with seed.

Laboratory Experiments with Mixtures

The laboratory experiments with the mixtures included five mixtures of legumes and cereals (Table 2). Two of these cereals (oat and rye) are commonly included with winter-hardy legumes in pre-made, commercially available mixtures in California. A 10-kg batch of each mixture was made by combining the appropriate weights of seed in a plastic tub with an approximate capacity of 36 or 70 L. Each mixture was thoroughly mixed by hand in the tub and poured into a 18.9-L bucket. The mixture was further homogenized in the bucket by a worker whose hands were inserted to the bottom of the bucket to lift the seed to the top of the bucket 10 times. A cup was calibrated to scoop 100 g of seed from the bucket using the same procedure and equipment in the timed comparison (Fig. 1). After calibrating the cup, the seed in the bucket was remixed 10 times, and 81 or 91 cups of seed were scooped from the center of the bucket. During the scooping procedure, the first scoop and every 10th scoop thereafter was set aside for analysis of total seed weight and the weight of each mixture component. Sieves were used to separate the seed types

Table 2. Description of the five mixtures used in the laboratory experiment to evaluate the effect of scoop number on mixture composition.

Mixture	Composition by seed weight, %†
1	90% faba bean, 10% rye
2	90% faba bean, 10% oat
3	90% faba bean, 10% barley
4	90% common vetch, 10% rye
5	35% faba bean, 30% common vetch, 25% pea, 10% rye

† The 1000-seed weights of pure seed in g were faba bean (338), rye (17), oat (24), barley (34), common vetch (53 in Mixture 3, 74 in Mixture 4), and pea (235).

before weighing. After obtaining the weights of the mixture components, the seed was remixed 10 times by hand as described above and the procedure was repeated 4 times for each mixture.

Statistical Analysis

All analyses were conducted with SAS version 9.2 (SAS Inst. Cary, NC). In the field experiments, the 95% confidence intervals of the seed weight of the seed packets that were loaded into the cones and the resulting cover crop population densities were calculated with the CLM option in the MEANS procedure. A separate ANOVA was conducted for each experiment with the MIXED procedure with the DDFM = KR option to determine the significance of the seed preparation method (method) and seeding rate (rate) and the method × rate interaction. Replicate was considered a random effect, and fixed effects were method, rate, and method × rate. To meet the equal variance assumption of ANOVA, the population density data for the mustard and common vetch experiments were log transformed before analysis. The timing experiments were analyzed with the MIXED procedure as described above with replicate as a random effect and method as a fixed effect. The MEANS procedure was used to obtain 95% confidence interval for the mixtures data from the laboratory experiments to compare the mixture composition in each scoop with the ideal composition; the ideal composition is the composition assuming no seed segregation. The MIXED procedure was used for pairwise comparisons of mixture composition from the first scoop at the top of the bucket with successive scoops using a Dunnett test or Dunnett–Hsu test with a familywise error rate of $P \leq 0.05$; replicate was random effect and scoop number was a fixed effect. The number of seed of each mixture component for each retained scoop was calculated based on the weight of each seed component in the scoop and on the 1000-seed weights. The seeding density (seed m^{-2}) was calculated assuming that each scoop of seed was loaded into the CP used for the field experiments.

RESULTS AND DISCUSSION

Monoculture Field Experiments

The seed packet weights prepared by scooping were usually less than the target weight (Table 3). The average error rate of the scooping method across all monocultures and seeding rates was 1.8%, and ranged from 0.5 to 4.7% for the highest seeding rates of rye and faba bean, respectively. Seed size did not affect the accuracy of the scooping method as illustrated by the similar error rate in the smallest seed (mustard, 2.0%), medium-sized seed (common vetch, 1.3%), and largest seed (faba bean 2.7%). Furthermore, seeding rate did not have a consistent effect on the accuracy of the scooping method. The accuracy of the scooping

Table 3. Weight of seed in packets for the monoculture cover crop experiments prepared by scooping with a calibrated cup.

Experiment	Target seed packet weight, g	Scooped weight, g†	Percent error‡
Faba bean	100	97.6 ± 3.1	2.5
Faba bean	200	199.3 ± 4.2	1.0
Faba bean	400	380.9 ± 8.2	4.7
Vetch	40	39.9 ± 0.6	0.9
Vetch	80	81.2 ± 2.6	1.8
Vetch	160	159.3 ± 3.3	1.1
Mustard	10	9.7 ± 0.2	3.0
Mustard	20	20.2 ± 0.8	1.0
Mustard	40	39.4 ± 1.5	2.1
Rye	60	59.3 ± 1.5	1.3
Rye	120	121.3 ± 0.9	1.1
Rye	240	241.2 ± 1.5	0.5

† Mean ± 95% confidence interval of the seed packets from the scooping method before planting.

‡ Percent error rate is the average across the four replicates and was calculated as follows: Percent error = (|target packet weight × scooped weight|)/target packet weight × 100.

method is impressive considering (i) that a single randomly chosen weighed sample was used to calibrate each cup and that the cup calibration was not further adjusted, (ii) that a relatively crude method (i.e., horizontal shaking) was used to level the seed along the brim of the cup, and (iii) that a relatively large range in target seed packet weights was evaluated (i.e., 10–400 g).

The population densities of the monocultures ranged from the 20 plant m^{-2} with faba bean at the lowest seeding rate to more than 700 plants m^{-2} for the highest seeding rate of rye (Fig. 2). The cover crop densities as percentage of pure live seeding rates were 96 (faba bean), 56 (mustard), 60 (rye), and 81 (common vetch) averaged across seeding rates. The causes of the low emergence in mustard and rye (Fig. 2C, D) were not investigated, but with mustard, were likely related to a deeper than optimal planting depth. The recommended planting depth for mustard cover crops is 0.6 to 1.9 cm (Clark, 2007); however, a study with canola (*Brassica napus* L.) reported that the effect seeding depth (19 mm vs. 38 mm) only reduced emergence in some North Dakota environments (Hanson et al., 2008). Given the relatively large variability in mustard density within seed packet preparation method (Fig. 2C), yet the relatively small difference in weighed vs. scooped seed packets of mustard (i.e., 1–3%, Table 3), it is highly unlikely that seed packet preparation method would have affected mustard density even at an optimal seeding depth. The seeding depth problem with mustard illustrates the challenge of seeding mustard through double disc openers on a drill; it would have been preferable to divert the mustard seed from the cones into tubes that would place the seed on the soil surface immediately behind the disc openers and allow it to be covered by the press wheels as if it had originated in a small seed hopper. Lastly,

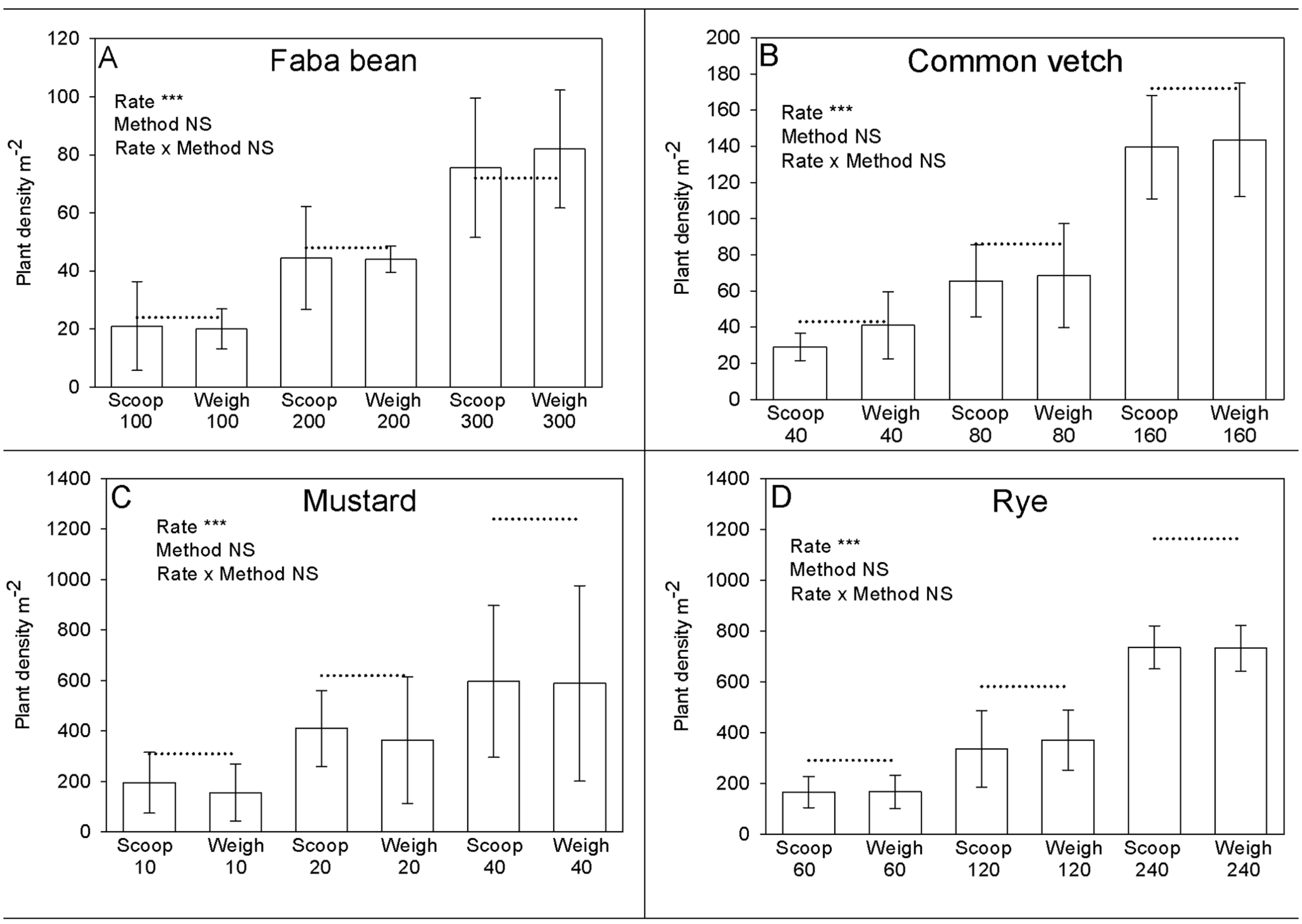

Fig. 2. Effect of seed preparation method and seeding rate on population densities of faba bean (A), common vetch (B), mustard (C), and rye (D). Horizontal dotted lines indicate the pure live seeding density in seed packets with target weights (g) for faba bean (100, 200, 300), common vetch (40, 80, 160), mustard (10, 20, 40), and rye (60, 120, 240). Bars are the means and 95% confidence intervals. Within each cover crop the significance of rate, method, and rate × method are indicated where * is significant at $P \leq 0.001$, and NS is not significant.**

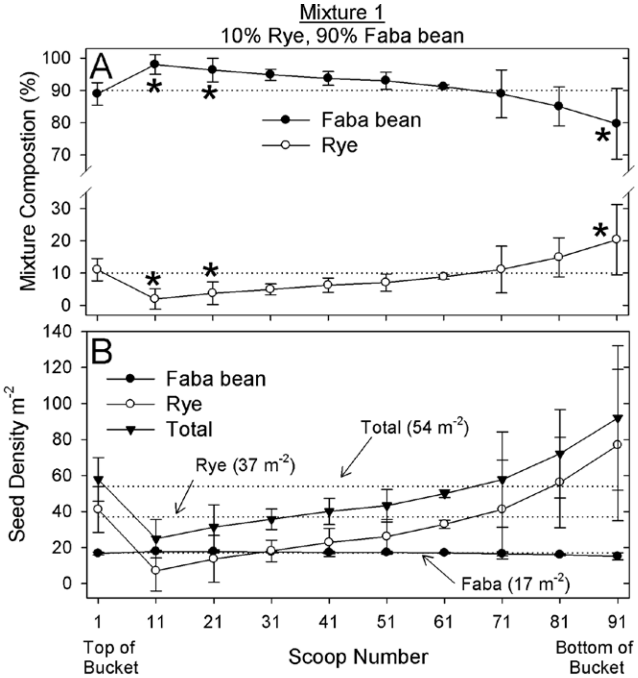

Fig. 3. Composition (A) and seed density (B) of a mixture of 10% rye and 90% faba bean scooped with a cup at varying depths from the top to the bottom of a bucket of seed; the mixture percentages are by seed weight. The cup was calibrated to scoop 100 g of seed. The horizontal dotted lines indicate the ideal composition (A) and seeding density (B) if there was not segregation of mixture components in the bucket. The seed densities are the expected densities if the scooped seed was planted from a planter with one cone that distributes the seed among seven lines spaced 15 cm apart in a plot that was 12.4 m long. Points are means ± 95% confidence intervals. An * adjacent to a mean indicates that the mean was significantly different from scoop number 1 within each component, based on a familywise error rate of $P \leq 0.05$. Significant differences are only shown for mixture composition (A) but followed the same pattern for seed density.

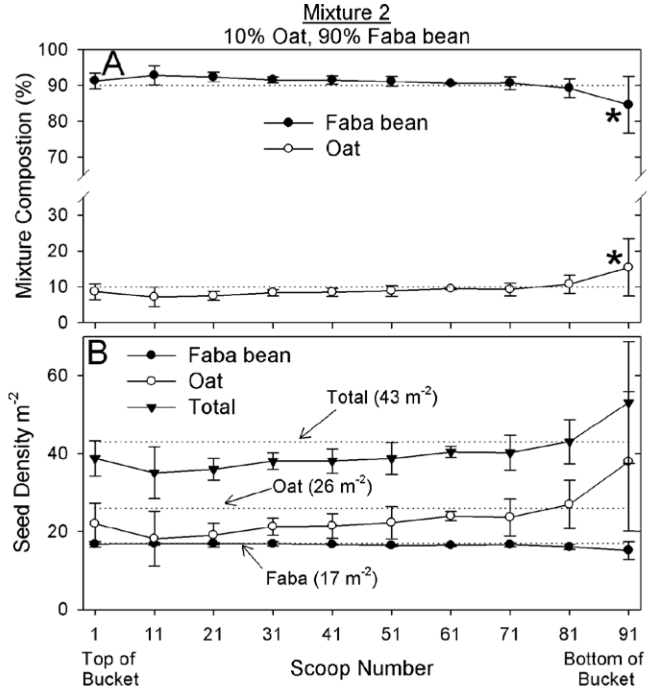

Fig. 4. Composition (A) and seed density (B) of a mixture of 10% oat and 90% faba bean scooped with a cup at varying depths from the top to the bottom of a bucket of seed; the mixture percentages are by seed weight. The cup was calibrated to scoop 100 g of seed. The horizontal dotted lines indicate the ideal composition (A) and seeding density (B) if there was not segregation of mixture components in the bucket. Points are means ± 95% confidence intervals. The seed densities are the expected densities if the scooped seed was planted from a planter with one cone that distributes the seed among seven lines spaced 15 cm apart in a plot that was 12.4 m long. An * adjacent to a mean indicates that the mean was significantly different from scoop number 1 within each component, based on a familywise error rate of $P \leq 0.05$. Significant differences are only shown for mixture composition (A) but followed the same pattern for seed density.

the distance from the pure live seeding rate to the upper confidence limit of plant density increased with seeding rate in mustard and rye, suggesting that plant competition increased with seeding rate and may have reduced emergence.

As expected, plant density increased significantly with seeding rate (Fig. 2). Seed preparation method had no effect on the plant density of the cover crops. The method × rate interaction was never significant, which indicates that seed preparation method did not vary with rate. The 95% confidence intervals illustrate considerable variation in the plant densities of all cover crops.

Weighing Versus Scooping Time

The scooping method of preparing seed packets was significantly faster than the weighing method by a factor of 2.7 for faba bean and mustard, and 2 for oat. The round shape of faba bean and mustard seed made them more difficult to weigh because their seed flowed more readily onto the balance during weighing. A person preparing the seed continuously at the pace in the timed experiments, would take 32 min to prepare 100 seed packets by weighing vs. 13 min by scooping, averaged across all seed types.

Laboratory Experiments with Mixtures

The first scoop taken from the bucket was representative of the ideal composition that indicates that the seed was uniformly mixed before scooping began and that minimal segregation of components had occurred in the bucket (Fig. 3A through 7A). However, the confidence interval range was largest in Mix 1 (Fig. 3A) and 5 (Fig. 7A), intermediate in Mix 2 and 3 (Fig. 4A, 5A), and smallest in Mix 4 (Fig. 6A). The larger confidence intervals at scoop 1 indicate greater viability in Mix 1 and 5 and a greater potential for seed segregation. The percentage of smaller seed components declined from scoop 1 to 11, compared with the percentage of the larger seed components that increased. These patterns were most obvious in Mix 1 and 5 where significant differences occurred. For example, Mix 1 had an average of 11% rye and 89% faba bean at scoop 1 vs. 2% rye and 98% faba bean at scoop 11 (Fig. 3A). The gradual and consistent increase in the smaller seed with successive scoops after scoop 11 indicates that the smaller seed had segregated to the bottom of the bucket. The increase in the percentage of the smaller seed component deeper in the bucket was most apparent with rye in Mix 1 and 5.

Seed weight is a common measure of seed size (Harper et al., 1970) and appeared to be the main factor affecting the seed segregation patterns of the mixture components. For example, there were two major segregation patterns in Mix 5 including one for rye and common vetch with 1000-seed weights of 17 and 74 g respectively, and another for pea and faba beans with 1000-seed weights of 235 and 338 g, respectively (Fig. 7). The

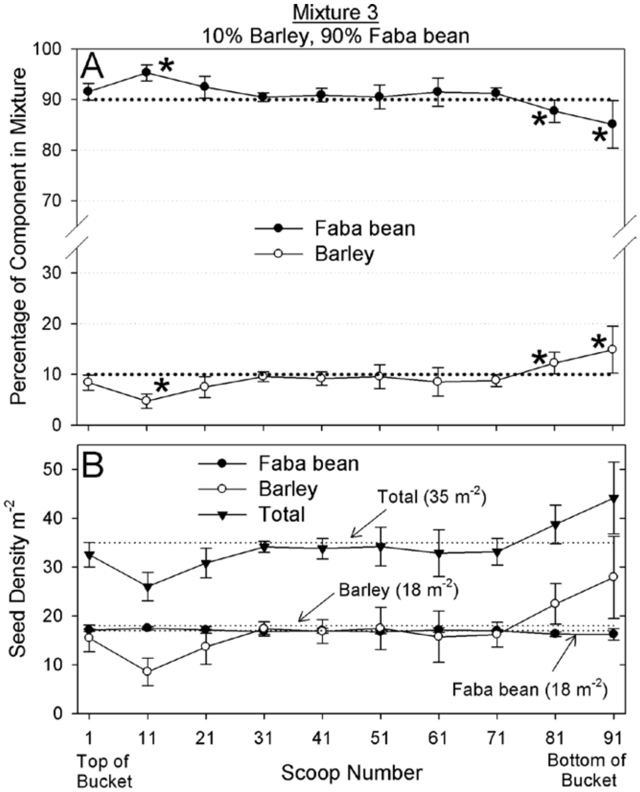

Fig. 5. Composition (A) and seed density (B) of a mixture of 10% barley and 90% faba bean scooped with a cup at varying depths from the top to the bottom of a bucket of seed; the mixture percentages are by seed weight. The cup was calibrated to scoop 100 g of seed. The horizontal dotted lines indicate the ideal composition (A) and seeding density (B) if there was not segregation of mixture components in the bucket. Points are means ± 95% confidence intervals. The seed densities are the expected densities if the scooped seed was planted from a planter with one cone that distributes the seed among seven lines spaced 15 cm apart in a plot that was 12.4 m long. An * adjacent to a mean indicates that the mean was significantly different from scoop number 1 within each component, based on a familywise error rate of $P \leq 0.05$. Significant differences are only shown for mixture composition (A) but followed the same pattern for seed density.

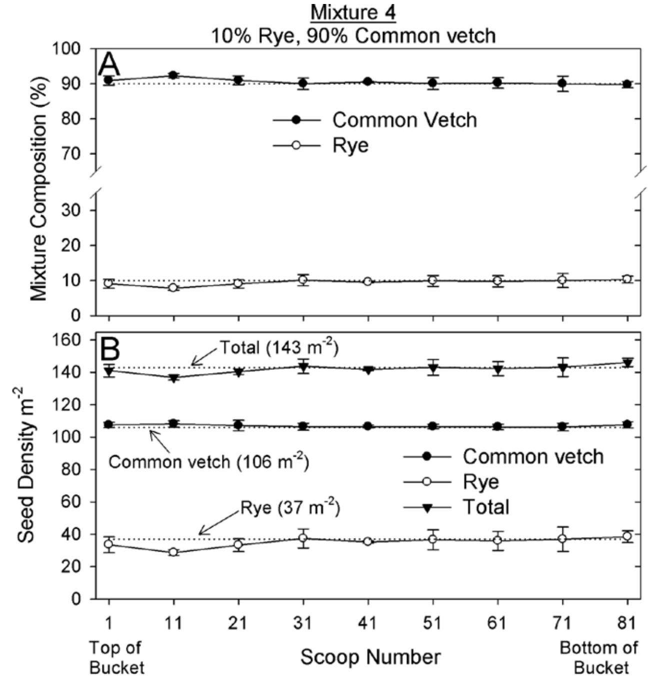

Fig. 6. Composition (A) and seed density (B) of a mixture of 10% rye and 90% common vetch scooped with a cup at varying depths from the top to the bottom of a bucket of seed; the mixture percentages are by seed weight. The cup was calibrated to scoop 100 g of seed. The horizontal dotted lines indicate the ideal composition (A) and seeding density (B) if there was not segregation of mixture components in the bucket. Points are means ± 95% confidence intervals. The seed densities are the expected densities if the scooped seed was planted from a planter with one cone that distributes the seed among seven lines spaced 15 cm apart in a plot that was 12.4 m long. There were no significant differences in the mixture composition or seed density between the first scoop and any other scoop.

effect of seed size on segregation is further illustrated where faba bean was mixed with rye vs. oat; significantly more segregation occurred with the smaller-seeded rye (17 g 1000 seeds^{-1}) than oat (24 g 1000 seeds^{-1}) (Fig. 3, 4). However, other factors such as seed length or shape also appear to affect segregation because barley seeds (34 g 1000 seeds^{-1}) are heavier than oat seed, yet barley segregated more than oat when mixed with faba bean. Seed lengths were 6.3 mm (rye), 9.2 mm (barley), and 11.4 mm (oat). Segregation of mixture components is a common industrial problem that has received extensive research attention because of its implications with a variety of materials (i.e., food, pharmaceuticals, minerals) (Tang and Puri, 2004; Shi et al., 2007). Two types of segregation likely occurred in the more segregation-prone seed mixtures including (i) the "Brazil nut effect" whereby larger particles rise to the top of a mixture (Rosato et al., 1987) and (ii) sifting segregation whereby smaller particles move downward in voids between larger particles (Johanson et al., 2005).

The practical effects of changes in the percentage of seed components in the mixtures with successive scoops from the bucket were more apparent when considered on the basis of seed density m^{-2} (Fig. 3B through 7B). For example, the decline in rye from scoop 1 to 11 would result in almost a sixfold decline for rye (41 to 7 seeds m^{-2}), compared with a minimal increase from 17 to 18 faba bean seeds m^{-2}. These results reveal major problems with using the scooping method to prepare seed packets from pre-made mixtures (Mix 1, 3, and 5) because the number of seeds of each component varied with scoop number at both the top and bottom of the bucket. However, the data also indicate that scooping may be a reliable method to prepare pre-made mixtures where seed segregation was only significant at the bottom of the bucket.

Several factors in addition to seed weight, length, and shape may affect seed segregation in mixtures including mixture composition, volume of the calibrated cup, and quantity of the pre-made mixture. Given the plethora of factors that may affect seed segregation, the scooping method should only be used to prepare seed packets from a pre-made mixture after testing for seed segregation. Comparing the weights of scooped samples of pre-made mixtures from various depths in a bucket is a relatively simple and fast way to determine a mixture's segregation potential during scooping. This is illustrated with Mix 1 where the weight of the scooped seed increased with scooping depth as the smaller seed sifted to the bottom of the bucket (Fig. 8); although the volume of the calibrated scoop was not measured, the data illustrates an increase in the bulk density from scoop 11 to 91. Furthermore, the variability in mixture composition of the first few scoops of seed is also a good indicator of the seed segregation tendency of a mixture. For example, Mix 4 that did not segregate significantly had the least variation in mixture composition at scoop 1 (Fig. 5).

Suggestions for Scooping

The following suggestions will simplify the scooping process and prevent problems when working with mixtures.

1. Have a range of tube lengths available (Fig. 1) to hasten the process of selecting a suitable cup length to calibrate to the desired seed packet weight. For example, a set of 6-cm diameter tubes in 1-cm increments from 4 to 18 cm will make cups that scoop 10 to 300 g of seed for a variety of crops.
2. Secure the stopper in the bottom of the cup with a hose clamp to prevent stopper movement while scooping. Although duct tape was used to secure the stoppers for preparing seed for the monoculture field experiments, a hose clamp is easier to adjust.
3. Scrape the brim of the cup on a tube attached to a bucket to conserve seed, minimize spillage, and improve uniformity (Fig. 1).
4. Use a funnel to reduce spillage while transferring the scooped seed from the cup into a seed packet.
5. Avoid splitting a large batch of a pre-made mixture into small quantities by pouring off the desired quantity into another container. Pouring mixtures with different size particles causes segregation due to the "avalanche effect" whereby larger particles flow out the source container first (Makse et al., 1998). For example, splitting a 10-kg batch of Mix 2 in two batches by pouring resulted in 11% oat in the source bucket and 9% oat in the receiving bucket (data not shown). Therefore, if two 5-kg batches of a mixture are needed for scooping, it would be best to mix two separate 5-kg batches rather than split a 10-kg batch.
6. Thoroughly homogenize pre-made mixtures by hand before scooping. Tumbler mixers such as cement mixers with baffles in the periphery of the tumbler cause radial segregation (Shi et al., 2007; Vargas et al., 2008) and thus would be unlikely to homogenize cover crop seed mixtures.
7. Avoid scooping from the bottom of the bucket for pre-made mixtures. The data presented here suggests that the bottom 20% of a bucket of seed should be avoided even with mixtures such as Mix 2 that remained relatively homogenous (Fig. 4).

CONCLUSIONS

Scooping seed with a calibrated cup was evaluated as a time-saving alternative to weighing for preparing seed packets of cover crop monocultures and mixtures for planting with a CP. Preparing seed packets was at least two times more time-consuming by weighing than scooping. There were no differences in the resulting population densities of the monoculture cover crops over a range of seeding rates from seed packets prepared by scooping vs. weighing. Cups can easily be calibrated to scoop within 1% of the desired weight by adjusting the cup volume with several weighed samples and scraping the brim of the cup to remove excess seed. The scooping method is an accurate method to prepare seed of monoculture cover crops and mixture

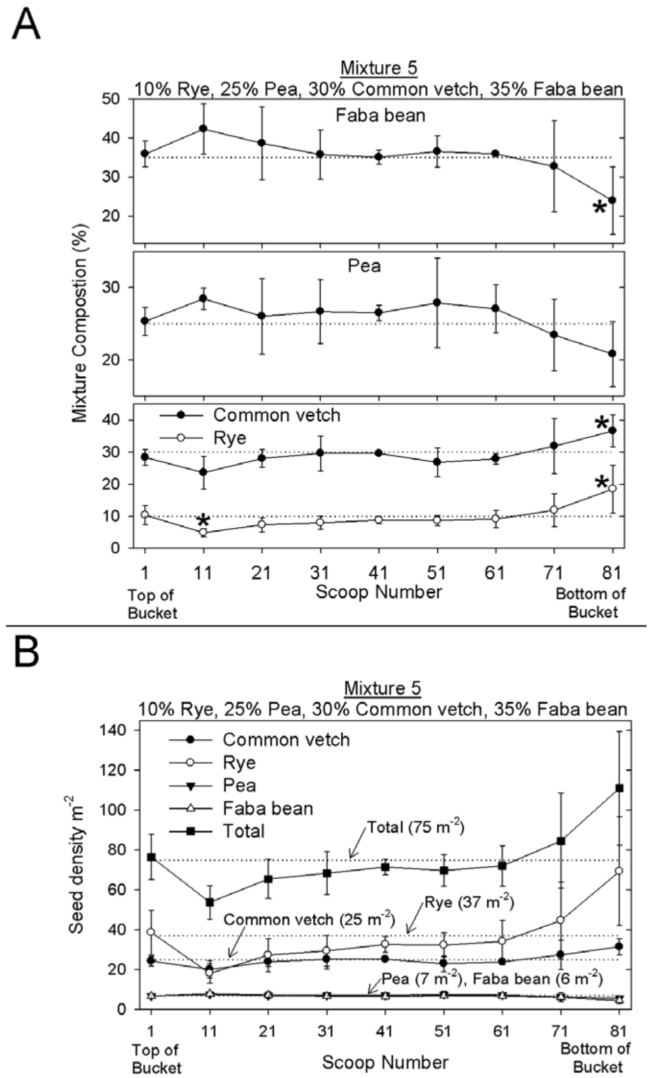

Fig. 7. Composition (A) and seed density (B) of a mixture of 10% rye, 25% pea, 30% common vetch, and 35% faba bean scooped with a cup at varying depths from the top to the bottom of a bucket of seed; the mixture percentages are by seed weight. The cup was calibrated to scoop 100 g of seed. The horizontal dotted lines indicate the ideal composition (A) and seeding density (B) if there was not segregation of mixture components in the bucket. The seed densities are the expected densities if the scooped seed was planted from a planter with one cone that distributes the seed among seven lines spaced 15 cm apart in a plot that was 12.4 m long. The pea and faba bean lines, and their corresponding ideal densities are overlapping in the seeding density plot. Points are means ± 95% confidence intervals. An * adjacent to a mean indicates that the mean was significantly different from scoop number 1 within each component, based on a familywise error rate of $P \leq 0.05$. Significant differences are only shown for mixture composition (A) but followed the same pattern for seed density.

components for planting with a CP, but should only be used with pre-made mixtures after verifying that scooping does not cause significant segregation of the components. Based on the result of this study, the scooping method is being used to prepare seed packets for field studies with cover crops at the USDA-ARS in Salinas, CA. The scooping method could be used in the field to load seed into CP without the need to prepare seed packets in advance. This study provides the first quantitative information on seed segregation in cover crop mixtures and indicates that segregation patterns are influenced by seed weight

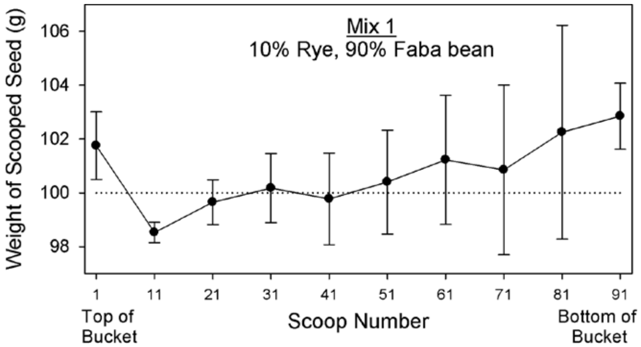

Fig. 8. Weight of scooped seed of Mix 1 at various depths in a bucket. The mixture percentages are by seed weight. The cup was calibrated to scoop 100 g of seed as indicated by the horizontal dotted line. Points are means ± 95% confidence intervals.

and seed length. Future research should evaluate seed segregation in cover crop mixtures during planting to provide farmers and researchers with guidelines to develop mixtures that can be planted with a single pass with a standard grain drill.

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