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Producer participatory spring wheat variety evaluation for organic systems in Minnesota and North Dakota

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Summary

Organic producers in Minnesota and North Dakota, USA, indicated that they wanted to participate in hard red spring wheat (Triticum aestivum L. emend. Thell) variety evaluations. The objectives were to determine if a farmer–researcher developed scoring system could be used to rank wheat varieties for yield potential when grown in certified organic fields, identify views of organic producers about on-farm research, and identify the educational impact of the participatory variety evaluation process. Hard red spring wheat varieties were compared for grain yield at six locations on certified organic farms in Minnesota and North Dakota over a three-year period. A scoring system was developed and then used to identify the relative rank of adapted varieties for yield. Producers were asked to rank all varieties on a scale from 1 to 9, where 1 is lowest yield potential and 9 is highest yield potential. Producers were able to distinguish higher producing varieties as a group in 2003 and 2004. 'Oklee' a high yielding variety was ranked lowest in 2005. There was a significant linear relationship between producer ranking and yield ($P < 0.05$) even though producers could not pick the highest yielding varieties consistently in the field. The producer survey showed that grain yield, protein content, wheat scab resistance, leaf disease resistance, early seedling vigor, test weight and canopy closure were traits producers valued most in a variety. Heading date, impact on succeeding crops, straw and stubble production were ranked lower. Multi-year variety evaluation on certified organic land was highly valued by the producers surveyed. From an educational perspective, the exercise was successful in that producers had to observe individual varieties carefully in order to come to a consensus producer ranking. The model of participatory research can be used for a variety of field research projects and field days.

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Wheat grain quality response to tillage and rotation with field pea

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Summary

Preceding spring wheat (*Triticum aestivum* L.) with field pea (*Pisum sativum* L.) can enhance wheat grain yield in a wheat-pea (WP) rotation compared with continuous wheat (WW). The pea-rotation benefits to wheat grain quality are uncertain. A 6-yr study was conducted to determine if: (1) grain protein content, kernel weight, and test weight were enhanced for wheat in a WP rotation compared with WW, and (2) an interaction between cropping and tillage systems existed. The WP and WW systems were maintained in subplots within clean-till (CT), reduced-till (RT), and no-till (NT) whole plots arranged in a randomized complete block as a split plot in southwestern North Dakota, USA. Grain protein content of wheat averaged 160 g kg^{-1} and was unaffected by cropping system ($P > 0.05$). However, grain protein content was 10 to 30 g kg^{-1} lower under NT compared with CT, depending on the year. Kernels were heavier in two of six years in the WP rotation compared with WW. No difference in kernel weight was detected between cropping systems in the other four years. A consistent trend in kernel weight was not detected across tillage systems, and interactions between cropping and tillage systems were not observed for either grain protein content or kernel weight. A three-way interaction between cropping systems, tillage systems, and years was detected for grain test weight. These results failed to demonstrate a consistent pea-rotation benefit to wheat grain quality.

Impact of Fall-Seeded Cover Crops and Cover Crop Termination Method on Weed Biomass in the Ensuing Crop.

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SUMMARY

The inclusion of cover crops in a rotation can have several potential benefits, one of which is weed suppression in the following crop. Rye, and to a lesser extent wheat and hairy vetch, tissues are known to contain compounds which may inhibit the germination of small-seeded weeds when released into the soil during residue decomposition. Method of cover crop termination alters factors such as residue/soil contact and therefore may affect the extent of weed suppression. This study investigated the effect of five cover crop treatments (winter rye, winter wheat, hairy vetch, winter rye/hairy vetch intercrop and winter wheat/hairy vetch intercrop), in concert with three termination methods (disk, roller/crimper and wide sweep) on weed pressure in the subsequent cash crop. Overall, greater grass weed biomass occurred in crops following hairy vetch and winter rye than crops following winter wheat or the winter rye/hairy vetch intercrop. The effect of cover crop on broadleaf weed biomass in the subsequent crop was more complex, varying with termination method.

INTRODUCTION

Incorporating cover crops into a rotation is an excellent strategy for building organic matter and enhancing soil health, while also providing fertility and weed and disease suppression. The positive effects of cover cropping have been long recognized, but have grown in favor only recently as input costs rise. Cover crops are typically either relay-intercropped with a cash crop, or grown over a full season to provide a break in pest cycles. In either case, the crop provides an actively growing soil cover which suppresses weeds while still promoting soil microbiological activity, and serves as a source of organic matter and essential nutrients upon termination. Weed suppression occurs through direct competition while the cover is actively growing, as well as through the exudation of allelopathic compounds by some crops.

Allelopathic compounds are chemicals synthesized by growing plants that can suppress the germination of seeds of potential competitors. This suppression can occur not only while the crop is growing, as the chemicals are exuded from the roots of the plant, but can also persist after termination as these compounds leach from the crop residue. It is generally accepted that the allelopathic potential is greatest if the crop residue remains on the soil surface (Putnam et al., 1983). Generally, allelopathic chemicals are most effective in suppressing germination as seed size decreases. Many problematic weeds in agricultural systems produce large quantities of small, easily dispersed seeds, so enhancing the allelopathic effect of cover crop residues could provide weed suppression in the following crop, at least for a period of time long enough to endow the crop with a competitive advantage. Furthermore, most field crops will remain unaffected by allelopathy due to the somewhat larger seed size.

One crop most commonly cited for its allelopathic potential is rye, which is often used by organic growers as a weed suppressant and catch crop. Research suggests that allelopathic compounds synthesized by a rye cover crop may not only provide weed control while the crop is growing, but can remain effective germination-inhibitors of small-seeded weeds for some time after termination of the crop (Teasdale et al., 1991). However, incorporation of residues leads to more rapid decomposition and dissolution of these allelopathic compounds, as compared with leaving the residue on the soil surface, which allows the chemicals to leach more slowly from the residues (Putnam et al., 1983).

To harness the potential benefits of allelopathy, a roller/crimper has been used to terminate rye without disturbing the soil surface. The roller/crimper consists of a cylindrical drum with parallel chevron-shaped ridges which crush but do not cut the stalk of the growing crop, ideally resulting in firmly packed mulch on the soil surface into which the subsequent crop can be no-till seeded. This method can be used with other cover crops as well, and has achieved some success in several areas in the United States and abroad. However, it generally is necessary for rye (and many other crops) to have reached at least the onset of flowering before rolling can effectively kill the plant.

Mowing, or other tillage methods can be used for cover crop termination as well. However, the burying of potentially allelopathic residue that results from tillage is known to reduce its effectiveness as a weed control device, while the exposure and disturbance of the soil surface resulting from tillage may also create favorable conditions for weed seed germination. Soil disturbance also destroys soil structure, reduces moisture retention and enhances the breakdown of organic matter; therefore, minimal soil disturbance is often recommended as a strategy for improving soil quality. Unfortunately, tillage is heavily relied upon in organic and some low-input management systems to control weeds. The potential of cover crops to enhance soil quality and ameliorate the detrimental aspects of tillage is great, while termination of these crops without soil disturbance, and their potential for weed suppression could reduce dependence on tillage in the above-mentioned management systems.

Cover cropping is also a useful way to enhance soil fertility. In order to maximize the supply of nutrients added to the soil, leguminous cover crops are often incorporated into rotations, due to their ability to fix significant amounts of nitrogen. In fact, including a broad selection of crops in the rotation, as well as applying organic amendments, is an important strategy for increasing the organic matter content of the soil. The inclusion of combinations of low and high-quality crop residues is important because high quality, low C:N ratio materials decompose quickly, contributing very little to overall OM content. Lower quality residues, on the other hand, break down more slowly in the soil due to higher C:N ratios. These low-quality residues increase soil organic matter content but contribute very few potentially mineralizable compounds (Seiter and Horwath, 2004). Therefore a diversity of crop residues ensures sufficient organic C and N for humus formation and ultimately engenders a pool of potentially available nutrients that can become mobilized according to crop demand. The importance of organic matter additions, through the inclusion of cover crops in the rotation as well as manure or compost application, cannot be overestimated. In fact, research has shown that when 150 lb/ac of synthetic nitrogen fertilizer is applied to a corn crop, soil organic matter still supplies up to 70% of the N taken up by the corn (Omay et al., 1998). Furthermore, it is estimated that 20 to 70% of the soil cation exchange capacity is due to humic substances, which highlights the importance of organic matter for nutrient storage (Seiter and Horwath, 2004).

The potential of cover crops for weed control, combined with their ability to enhance fertility and soil quality while sustaining ecosystem services during periods of non-cash cropping, suggest many benefits if incorporated into cropping systems.   A potential fit for cover crops in the northern plains is seeding these crops post harvest and terminating in the spring prior to seeding a cash crop. The objective of the current study was to screen three different species for use as cover crops, including winter rye (WR), winter wheat (WW) and hairy vetch (HV) sown individually, as well as winter rye/hairy vetch (WR+HV) and winter wheat/hairy vetch (WW+HV) intercrops. Crops were evaluated specifically for their ability to reduce weed densities in a variety of subsequent cash crops (buckwheat, sweet corn and navy bean) without interfering with crop performance. A coincident goal of the study was to determine which method of termination - disking, wide sweep/noble blade, or roller/crimper - was most effective at killing the cover crop and also resulted in the least amount of weed pressure in the subsequent crop.

MATERIALS AND METHODS

Cover crop treatments consisted of winter rye (WR, 'Dakold'), winter wheat (WW, 'Ransom') and hairy vetch (HV, Common) sown individually as well as winter rye/hairy vetch (WR+HV) and winter wheat/hairy vetch (WW+HV) intercrops. All crops were seeded on September 20, 2007. The previous crop was oat and no fertilizer was applied prior to seeding the cover crops. The WR treatment was seeded at a rate of 140 lb/ac and the WW treatment was seeded at a rate of 150 lb/ac. In the WR+HV treatment rye was seeded at a rate of 112 lb/ac and vetch was seeded at a rate of 25 lb/ac, while in the WW+HV treatment wheat was seeded at 120 lb/ac and vetch at 25 lb/ac. Experimental design was a strip-split block and consisted of four randomized complete blocks with each block containing the three termination methods (disk, wide sweep, roller/crimper) established in random order. The cover crop treatments were established randomly in within each tillage treatment, even though tillage treatments were not applied until after the cover crop treatments were in place. Cover crop treatments were seeded in strips 10 ft wide and 42 ft long. All crops were seeded with a John Deere 750 low-disturbance drill into a no-till seed bed. Termination of cover crops was accomplished with the implements mentioned above being run through the cover crop treatments parallel to seeding direction.

Cover crop plant counts were taken from a $0.5/m^2$ area in the six cover crop treatments within one of the tillage treatments in each block on October 11, 2007. Counts were taken again in the spring to evaluate crop winter survival. First flowers were observed in rye and vetch on June 16, 2008 and in wheat one week later. Approximately one week was then allowed for the stands to reach full flower, at which time the covers were terminated. The WR, WR+HV and HV treatments were terminated on June 24, 2008 and the WW and WW+HV treatments were terminated on July 2, 2008. Cover crop biomass, along with grass and broadleaf weed biomass samples were taken from a $0.5/m^2$ area within the first six cover crop treatment plots in each block just prior to termination. Broadleaf, grass and cover crop samples were separated and weighed. Samples were then dried at 130° F for 3 to 4 days and reweighed to obtain dry weight and moisture content.

On July 3, 2008, cash crops were seeded in random order within each of the four blocks in 6 ft wide, 180 ft long strips perpendicular to tillage and cover crop strips with a cross-slot no-till drill. Cash crops initially consisted of buckwheat (‘Koma’), carrot (‘Nelson’), sweet corn (‘Earlivee’), navy bean (‘Vista’), pinto bean (‘Maverick’), and spring wheat (‘Parshall’), although the carrot, pinto bean and wheat treatments were abandoned due to extremely poor germination and crop performance. An unplanted check treatment was also included along with the cash crop strips to determine weed pressure in absence of crop competition. Seeding rates were as follows: buckwheat at a rate of 52 lb/ac, carrot at 9 lb/ac, sweet corn at 7.5 lb/ac, navy bean at 40 lb/ac, pinto bean at 50 lb/ac and wheat at 65 lb/ac.

Cash crop plant counts were performed on July 25 for buckwheat and navy bean and July 28 for sweet corn to determine stand biomass. Cash crops were harvested, along with grass and broadleaf weeds, on September 15 and 16. Crop, grass weed and broadleaf weed sampled were separated and dried at 130° F for 3 to 4 days before being weighed.

Statistical analysis was performed to determine the effect of cover crop and termination method on weed biomass in the subsequent crop and yield of subsequent crop. Analysis was conducted using SAS version 9.1 (SAS Institute, 2003), and consisted of a mixed model approach with block being a random factor and tillage, cover crop and main crop being fixed factors and the cover crop being nested within the tillage factor ($\alpha = 0.05$). Interaction effects were evaluated by pairwise comparisons of least squares means with mixed model ANOVA.

RESULTS

Cover Crop Survival and Biomass

Winter rye survival was 92% in the WR treatment and 90% in the WR+HV treatment. Hairy vetch survival was 74% when grown alone, 40% in mixture with winter rye and 37% in mixture with winter wheat. Winter wheat survival was 42% alone and 36% in mixture with hairy vetch.

The WW, WR and WR+HV cover crop treatments produced the most biomass, while the HV treatment produced the least (Fig. 1). The fact that the WW treatment produced the most overall biomass is interesting given the poor winter survival of winter wheat. It is likely that, due to dry spring conditions, the lower plant population of winter wheat reduced intraspecific competition and in turn enhanced performance, compensating for low density. The fact that the intercropping of hairy vetch with winter wheat seems to have reduced the overall amount of biomass produced supports this hypothesis. In terms of winter rye, on the other hand, overall biomass in the rye/vetch intercrop was virtually indistinguishable from the rye sole crop. Generally, the weed suppressant potential of cover crops increases with increasing cover crop biomass. More biomass results in a thicker mulch layer, which serves to physically inhibit weed seed germination, and increases the potential of allelopathic crops. In both cases the weed suppressant effect is most pronounced when the residue is left on the soil surface, rather than incorporated. Obviously, cover crops producing more biomass will also be more competitive with weeds while actively growing. Therefore, the performance of winter wheat, winter rye and the winter rye/hairy vetch intercrop indicate potential for cover cropping in this region based on the amount of biomass produced, as well as their potential allelopathic effect. Still, actual weed suppressant ability is the most important factor in this context.

Effect of Cover Crop on Grass Weed Biomass in Subsequent Crop

An overall effect of cover crop on grass weed biomass in the subsequent crop was observed, with more weeds by weight being present in crops following HV and WR covers than in crops following the WR+HV intercrop (Fig. 2). Termination method and main crop had no effect on grass weed biomass. Increased grass weed biomass under hairy vetch as compared with the hairy vetch/winter rye could be explained by vetch's lack of allelopathic effect, as well as the fact that the rapid decomposition of vetch (due to its low C:N ratio) could supply readily available nutrients for weed proliferation. The greater grass weed biomass after the winter rye sole crop compared to the winter rye/hairy vetch intercrop, on the other hand, is somewhat curious. If anything, it would seem logical that the winter rye sole crop would have an increased allelopathic effect in relation to the intercrop with hairy vetch. However, the interaction between the two crops and effects on soil ecology, microbial community structure and nutrient and moisture availability are likely to have had an influence on the reduced amount of grass weeds observed following the rye/vetch intercrop.

Effect of Cover Crop on Broadleaf Weed Biomass in Subsequent Crop

An effect of cover crop and termination treatments on broadleaf weed biomass in the subsequent cash crop was observed, while main crop, whether buckwheat, corn or navy bean, had no effect on broadleaf weed biomass. Weed biomass was greater following the HV treatment when terminated by the roller/crimper compared with weed biomass following HV in the two other tillage treatments (Fig. 3). This effect was also observed in the WW+HV treatment, while broadleaf weed biomass following the WW treatment was greater when terminated by the roller only in comparison with the wide sweep termination method. Broadleaf weed biomass in the WR+HV treatment was greater when the cover was disked than when it was rolled. To clarify, hairy vetch and the winter wheat/hairy vetch intercrop suppressed weeds in the subsequent crop to a greater extent when terminated with the disk or wide sweep than with the roller/crimper, while winter wheat suppressed weeds to a greater extent when terminated with the wide sweep than when terminated with the roller. The winter rye/hairy vetch intercrop, on the other hand, suppressed weeds in the subsequent crop to a greater extent when terminated with the roller/crimper than when terminated with the disk. Broadleaf weed suppression by winter rye was not affected by termination method.

Weed suppression was linked not only to the cover crop, but to the method by which the cover was terminated. In the case of the HV treatment, broadleaf weed control was reduced in the subsequent crop when the vetch was terminated by the roller. This may be a corollary of the rapid breakdown of the vetch residue and the minimal mulch that was therefore available to smother weed seedlings. In this case, performing tillage provided conditions less conducive to weed germination or survival, a fact that could be attributed to the exposure and subsequent desiccation of weed seeds resulting from tillage, especially given the extremely dry conditions. Furthermore, within the roller termination treatment, broadleaf weed biomass was greater following vetch than any other cover crop.

Given that it has been documented that rye, wheat and hairy vetch produce allelopathic compounds (Barnes et al., 1987, Putnam et al., 1983 and White et al., 1989), the fact that less broadleaf weed biomass was recovered from roller terminated treatments including rye or wheat could suggest a greater allelopathic effect from these crops. However, it is likely that this could again be due to the fact that the greater abundance of residues resulting from the other crops physically suppressed weed seed germination to a greater extent. In fact, in a similar study, Teasdale et al. (1991) found very little difference in the ability of rye and hairy vetch residues to suppress weeds in a subsequent corn crop, and identified the amount of biomass as the major factor in the extent of weed suppression.

Interestingly, within the four cover crop treatments that included a cereal, there was not a consistent reduction of subsequent weed biomass when terminated with the roller as compared to the other termination methods. For instance, while in the WR+HV treatment reduced broadleaf weed biomass was found subsequent to rolling as opposed to disking, the method of termination of the WR cover crop had no effect on subsequent weed biomass. Furthermore, in the WW cover crop more weed biomass was subsequently recovered in the roller treatment than in the wide sweep treatment and in the WW+HV cover crop weed biomass was greater following the rolling than following either of the other two termination methods. Any effect of allelopathy as affected by tillage is therefore difficult to ascertain from these results, and in fact the positive effects of reduced till such as greater moisture retention may actually be a factor in the increased weed biomass present after rolling as opposed to the other termination methods.

Effect of Cover Crop on Subsequent Crop Biomass

Due to extremely dry conditions and the late date of planting there was no harvestable crop following any of the cover crop treatments. However, crop biomass was collected at the same time as weed biomass. No direct effect of cover crop on main crop biomass was observed, although there was a termination method effect on overall main crop biomass. Regardless of cover crop, all crops tended to yield better after the wide sweep termination treatment, even though biomass was very low in all cases (Table 1). This could be attributed to the effect of slight disturbance on soil biology. The minimal soil disturbance occurring with the wide sweep could have stimulated mineralization by aerating soil and bringing plant debris into closer contact with the soil. At the same time, this implement still left the majority of the plant residue on the soil surface, which could have led to increased moisture retention compared with disk tillage.

The need to defer rolling until flowering to prevent cover crop regrowth delayed planting of the main crop to an extent that severely hampered development. Lack of rainfall was a prominent factor in reducing crop performance, while diminishing day length and a limited growing season also played a role. In a year with normal precipitation it is possible that cover crop flowering would be significantly earlier and therefore allow for earlier seeding of the cash crop. This would obviate concerns related to day and season length but given that dry conditions are common in the latter part of the growing season in this region the availability of moisture for the cash crop would still be of concern. The benefit of heavy residue on the soil surface that results from no-till termination of the cover crop would be negligible if the cover had exhausted available soil moisture. Termination methods involving tillage could potentially be used to kill cover crops earlier in the season than could be done with the roller/crimper, allowing for early seeding of the cash crop, and possibly better utilization of spring rains. High-residue implements would be required to maximize soil cover, but this method (as with any tillage event) would be at least somewhat detrimental to soil structure and reduce water infiltration and storage, especially over time.

CONCLUSION

These results indicate that there was no cover crop or cover crop mixture that clearly suppressed all weeds to a greater extent than any other in the subsequent crop. Relative to hairy vetch alone covers including winter rye and winter wheat showed some potential in suppressing grass weeds, as well as broadleaf weeds in the subsequent crop when terminated by the roller. Whether this was an allelopathic effect, an effect on soil biology or nutrient availability, or simply a physical effect of no-till negating conditions necessary for weed seed germination is unclear. There was also no termination method that was clearly preferable. Conclusions as to the effect of cover crop on subsequent cash crop are difficult to make given the extremely dry conditions and the late date of planting. However, cash crops tended to fair best following the wide sweep termination method, for reasons discussed above.

This study also suggests that a cropping system in which covers are fall-seeded and spring-terminated may not be the best option for the northern plains, given precipitation and season length limitations. However, this study has only occurred in one year, and an extremely dry year at that, so strong conclusions cannot be drawn. If cover crops could in fact be terminated earlier the system could have potential in this region, and ultimately further research is necessary to identify whether this system of cover cropping or another is the best strategy for enhancing weed control while maintaining soil fertility and minimizing moisture loss.

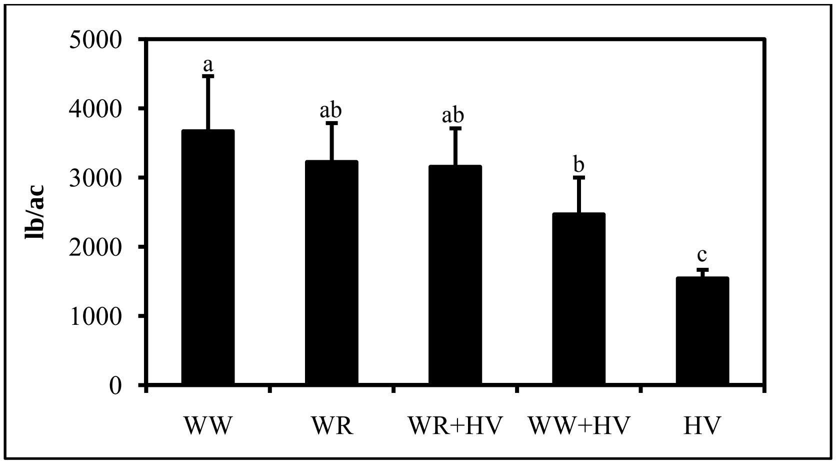

Figure 1. Overall biomass generated by cover crops.

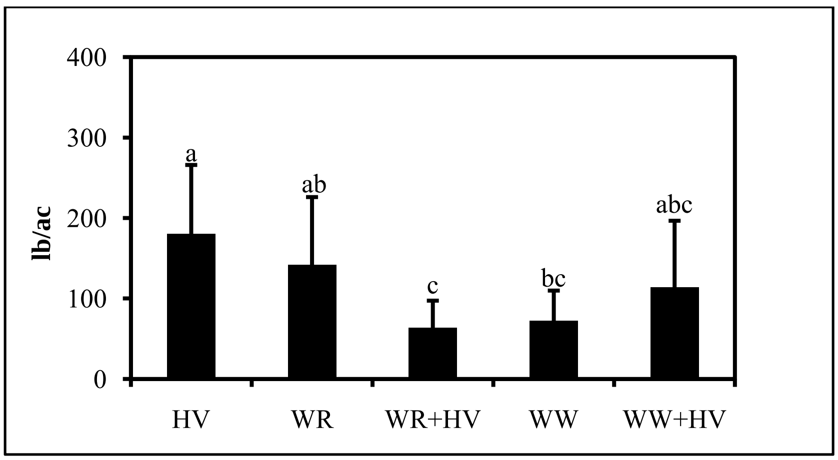

Figure 2. Grass weed biomass in subsequent crop as influenced by cover crop. Quantities with the same letter do not differ.

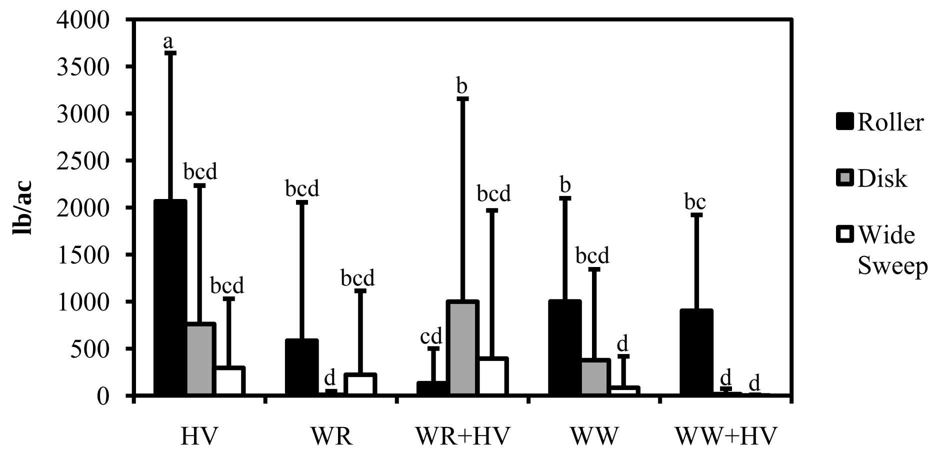

Figure 3. Broadleaf biomass in subsequent crop as influenced by cover crop and termination method. Quantities with the same letter do not differ.

Table 1. Overall main crop biomass (buckwheat, corn and navy bean) as affected by cover crop and termination method. Quantities with the same letter do not differ.

Termination Method	Cover Crop	Overall Main Crop Biomass
		— lb/ac —
Wide Sweep	HV	535.61a
Wide Sweep	WR	413.56ab
Disk	WR+HV	379.06b
Wide Sweep	WW	373.08b
Wide Sweep	WR+HV	319.49bc
Wide Sweep	WW+HV	278.42bcd
Disk	WR	272.62bcd
Disk	WW	265.75bcde
Disk	HV	212.78cdef
Disk	WW+HV	202.29cdef
Roller	WR+HV	130.97defg
Roller	WW+HV	117.20efg
Roller	WR	96.43fg
Roller	WW	45.26g
Roller	HV	6.51g

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An Efficacy Trial of Potential Herbicides for Use in Organic Systems.

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SUMMARY

Non-synthetic herbicides are herbicides utilizing naturally-occurring active ingredients for weed control. Under the National Organic Program, a small number of these herbicides have been approved for application on certified organic crop land (USDA AMS, 2002). These herbicides may provide an important tool for weed control in organic systems, if they prove effective. This study was concerned with evaluating the efficacy of three of these weed control products and to establish recommended rates for these products.

The three weed control products evaluated were corn gluten meal, vinegar and Racer. Corn gluten meal (CGM) has been shown to reduce germination of small-seeded weeds (Liu & Christians, 1996; Boydston et al., 2008), while vinegar (20% acetic acid) and Racer™ (ammonium nonanoate), have potential as burn down herbicides (Radhakrishnan et al., 2003; Webber III et al., 2008). All products were applied pre-plant and plots were subsequently seeded to pea. Grass weed abundance in pea was not affected by any of the products, while Racer reduced overall weed biomass according to visual evaluation and reduced broadleaf weed biomass compared to CGM.

INTRODUCTION

The National Organic Program, and most organic grower groups, place emphasis on preventative and cultural measures for weed control. These measures are an important component of a weed control strategy and can be effective in reducing severe weed problems, but in most cases weed control will still be necessary at some point during the growing season. Tillage is relied on heavily for weed control in many organic cropping systems, and can be an effective method of eliminating weeds. However, it is well known that excessive tillage can lead to problems with soil erosion and can negatively impact soil structure, organic matter content and humus formation. Furthermore, tillage can reduce soil water retention in comparison with no-till management, a fact that could have significant implications in low-rainfall, drought prone regions (Franzluebbers, 2004). Having a burn-down herbicide option could provide organic growers, especially those in dryland regions, with a useful tool for pre-emergence weed control that retains the benefits of minimized soil disturbance. A few herbicides are registered for use under the National Organic Standards, and therefore available to organic growers, although none of these products are presently labeled for use in North Dakota. These herbicides utilize naturally-occurring substances for weed control, such as clove and garlic oils, soap salts or acids, but little research has been conducted evaluating their efficacy.

Three non-synthetic, "natural" products were evaluated for their ability to control weeds in field pea. Racer™ bio-herbicide (Falcon Labs LLC, Wilmington, DE) Nature's Guide® Vinegar (Harvest Supply Company, Fort Worth, TX) and Nature's Guide® Corn Gluten Meal (Harvest Supply Company, Fort Worth, TX). The active ingredient in Racer is ammonium nonanoate (40%), a soap salt. Soap salts reduce the surface tension of water and lead to the collapse of guard cells around the stomata. As a result, the stomata become clogged and gas exchange is unable to occur, killing the plant (Ware and Whiteacre, 2004). Racer is a non-selective burndown herbicide. Vinegar containing high levels of acetic acid, well above the 5% acetic acid concentration of household vinegar, also has potential as a non-selective herbicide. Acetic acid works as a herbicide by causing the dissolution of cell membranes and the desiccation of the plant. Corn gluten meal is a byproduct of corn processing that has shown potential as a germination inhibitor of small-seeded plant species in research trials.

MATERIALS AND METHODS

The three products were all applied pre-plant. Treatments covered in this report include CGM at a rate of approximately 2.15 tn/ac, Racer at a rate of 14.4 lb ai/ac and Vinegar (20% acetic acid) at a rate of 35 gallons/acre. Corn gluten meal (CGM) was applied on May 20, Racer and Vinegar on May 27 and field pea was seeded on May 28. A weed-free and a weedy check treatment were included. Weed control was evaluated visually 1, 7, 14 and 21 days after treatment (DAT) and was reported as % control. Crop and weed biomass samples were taken on July 23 in all treatments except the weed free check, in which biomass samples were taken on August 5.

RESULTS

Visual assessments indicated a significantly greater overall control of weeds by Racer compared to CGM 1 DAT and compared to CGM and vinegar 7 DAT (Table 1). No significant difference in % control was observed at 14 or 21 DAT. Even though Racer application initially resulted in greater weed control, at most control was only 10.75%, which occurred 1 DAT.

Crop and weed biomass sampling indicated that CGM produced the least control of broadleaf weeds (Fig. 1). Racer suppressed broadleaf weed biomass compared with CGM and weedy check plots, but field pea growth was reduced in plots where Racer was applied compared with weed-free (hand-weeded) plots. The reduced pea growth in Racer plots compared with weed-free plots probably reflects greater competition from weeds in the Racer plots, even though no difference in broadleaf weed biomass was detected statistically between the Racer treatment (weed biomass ≈ 793 lb/acre) and the weed-free treatment (weed biomass ≈ 24 lb/ac). We were unable to detect any difference in broadleaf weed growth between plots where vinegar or CGM was applied and plots where no weed control was attempted. Grass weeds were low in abundance and showed to no response to treatment effects.

Table 1. Mean % weed control by three non-synthetic products based on visual assessment up to 3 weeks after treatment.

Product	Rate	1 DAT	7 DAT	14 DAT	21 DAT
		——— % Control ———			
CGM	2.15 tn/ac	0.00	1.00	0.00	0.00
Racer	14.4 lb ai/ac	10.75	4.50	3.75	2.50
Vinegar	35 gal/ac	5.25	0.00	0.00	0.00
LSD α=0.05		7.38	1.55	NS	NS
P		0.0359	0.0001	0.1757	0.4393

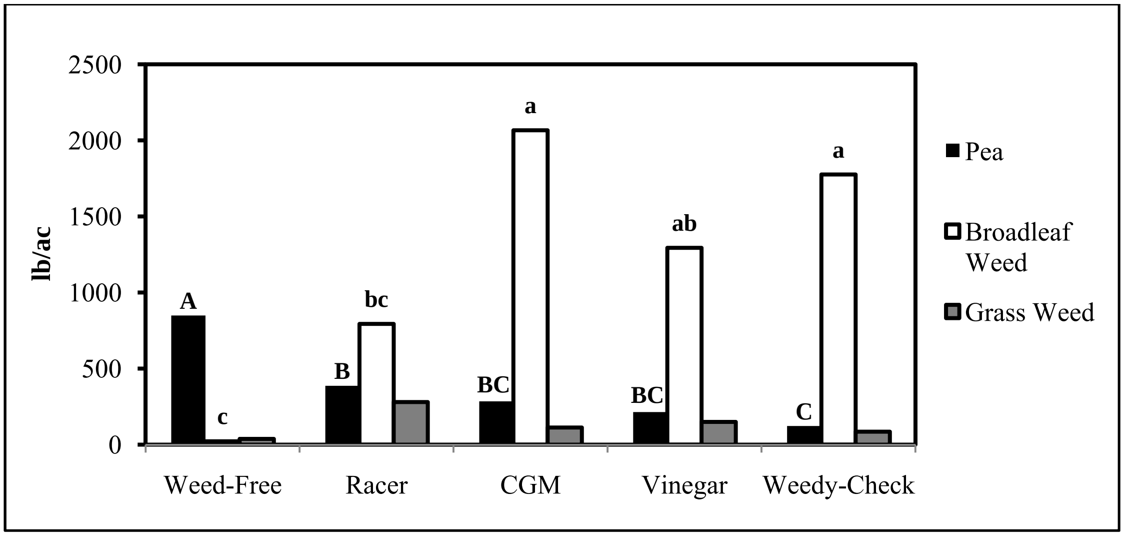

Figure 1. Average weed and crop biomass at harvest as affected by potential organic herbicides. Different uppercase letters denote significant between treatment differences in field pea biomass. Different lowercase letters denote significant between treatment differences in broadleaf weed biomass.

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Organic Vegetable Production in the North Central U.S: Linking Growth Traits to Adaptation and Weed Suppression

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SUMMARY

The potential for commercial vegetable production in western North Dakota is somewhat limited. However, gardeners, market growers or other, larger-scale operations with access to irrigation would benefit greatly from the identification of crop varieties that are well-suited to the particular climatic conditions. Very little work has been done in this area, and therefore, the objective of this study was to screen several varieties of three different vegetable crops (carrots, potatoes and sweet corn) for their suitability for production in western North Dakota. The linkage of performance with varietal growth characteristics is also of interest, and will be investigated further in years to come.

Yields were determined for all crops, carrots were ranked in terms of visual characteristics, and potatoes and carrots were subject to a taste test. Soil moisture and photosynthetically active radiation was measured in potatoes.Yields of all crops were low, resulting to a great extent from the extremely dry growing season in 2009. Of the carrot varieties screened, Hercules and Napoli generally performed the best, while Sugarsnax 54 was a poor performer. In potatoes, Superior and Red Gold showed some potential, and in sweet corn, Sugar Pearl was the best performer.

INTRODUCTION

Current production of fresh market vegetables in western North Dakota is limited, most notably due to climate conditions. However, interest in organic production and local food systems is growing. Organic farming methods seek to reduce dependence on off-farm inputs while stressing sustainable and ecologically sound production practices. Consonantly, the local foods movement seeks to create a food production and delivery system that identifies and fosters markets for locally grown crops. This system stresses local sourcing of foods whenever possible in order to strengthen regional economies and reduce the transportation time of food, while also striving to provide opportunities for small growers to compete for market share. As food safety and climate considerations gain precedence, the potential for small-scale vegetable production in the form of home or market gardens is anticipated in the region. Depending on the particular crop, availability of irrigation and site specific characteristics, larger scale production could conceivably be possible as well.

The climate of western North Dakota is characterized by a warm but short growing season, with a frost-free period of approximately 110-130 days. Growing season temperatures average 58-60° F, with a cool spring giving way to a relatively hot summer, averaging 16-24 days above 90° F each year. The climate is sub arid and prone to drought, especially later in the season. Average annual precipitation in western North Dakota is highly variable, but averages 16-17 in. Rainfall occurs predominantly in the spring, with cumulative April-June precipitation averaging 5 to 7 in., and decreases later in the season, with cumulative July-September rainfall averaging 4 to 5.5 in. Breezy conditions prevail throughout the season, with monthly maximum wind speeds averaging approximately 25 mph for April through June, and 23 mph for July through September.

Given the short growing season, low precipitation and windy conditions, a prominent issue for vegetable growers in the region is the identification of varieties and accompanying growth traits that are well suited to the climatic conditions of the region. Organic and conventional growers alike desire varieties that compete well with weeds, are resistant to disease and pest pressure, perform well under dry, windy conditions, and ultimately maintain high yields. Therefore, the objective of this study was to identify vegetable crop varieties suitable for production in this region. The performance of several varieties of three types of common vegetable crops, carrots, potatoes, and sweet corn was assessed using several variables. In future growing seasons, this experiment will be expanded to include not only other species of vegetables, but the number of measured parameters will also be broadened to facilitate the correlation of varietal growth traits with actual performance as evinced by resistance to weed, insect and disease pressure.

MATERIALS AND METHODS

Five varieties of potatoes, six varieties of carrots, and eight varieties of sweet corn were grown in separate experiments during the 2008 growing season (Table 1). Potatoes and carrots followed oat stubble fallow and sweet corn followed field pea. Soil type is a Parshall fine sandy loam. Experimental design was a randomized complete block with four replications for each crop. Seedbed preparation consisted of one pass with a tandem disk. Sweet corn was seeded in 32 in. rows on May 14 and carrots and potatoes were seeded on May 16 in 32 in. rows and 30 in. rows respectively. Corn was cultivated with a Lorenz 2 row "high trash" cultivator on June 23, and hoed and hand-weeded on June 27, July 2 and August 5 to control persist and in-row weeds. Weed control in carrots was performed by hoeing or hand-weeding as required on June 19, June 24, July 16 and August 18 and in potatoes on June 18, June 27, July 16 and August 18 by the same methods. Weeds occurring in alleys of the carrot study were controlled with a rototiller on June 21. Corn was thinned to a population of 18,000 plants/acre on June 27 and carrots were thinned to approximately 12 plants/row ft on July 22 and 23. Carrots were irrigated with an impact sprinkler on July 3 and August 6, resulting in approximately 2 to 3 in. of supplementary water. Harvest was performed by hand for all crops on August 25 in the case of sweet corn and August 29 in the case of carrots and potatoes.

Yield was determined for all crops, by harvesting a subsection of each whole plot and obtaining weights of the samples. Potato date of flowering was recorded, as was date of corn tasseling. Photosynthetically active radiation at soil surface was assessed in potato on July 21, July 28 and August 6. Three replicate readings were taken from each plot on each date below the plant canopy, while one above canopy reading was also taken in each plot. Volumetric soil moisture content was recorded in Potatoes on July 22, August 5 and August 19 with a Delta-T PR2 Profile Probe. This probe consists of a polycarbonate rod approximately 25 cm in diameter with electronic sensors at fixed intervals along its length. The probe is inserted to a consistent depth via seasonally permanent access tubes, installed on July 16 in each plot of two replicate blocks. Water content measurements were obtained at depths of 3 and 19 in.

Variables recorded in sweet corn included marketable ears/acre, plant height, cob length, cob diameter and number of kernel rows. Early season vigor was also recorded in corn on June 19. This was accomplished by walking through the study and visually ranking the varieties as -1, 0 or +1, which referred to below average, average and above average in terms of vigor, respectively. This procedure was repeated twice, once earlier and once later in the day, and the scores were averaged.

Carrot root length and diameter was recorded, while carrot roots were also visually ranked in categories of "root condition", which referred to the extent of cracking, blemishes and branching, "uniformity", which referred to the consistency of the root appearance within varieties, "true to type", which referred to the extent of similarity between the sample and the varietal standard, and "visual appeal", which described the overall attractiveness of the roots. A "size" category was also included, which pertained not to relative size differences between varieties, but to the extent to which variety best represented an acceptable fresh market carrot size in the opinion of the individual performing the rankings. Rankings were performed by randomly selecting ten roots from each variety, visually assessing the qualities described above and ranking on a scale of 1 to 6 (one being the best, six being the worst). Two individuals performed the rankings separately and the scores were averaged.

A taste test was also undertaken with harvested potatoes and carrots. Approximately 5 lbs of potatoes and 10 carrots were selected; carrots were peeled, cut into uniform wedges and served raw while potatoes were baked and served with skins. Varieties were randomly assigned a letter that only the test administrator was aware of and participants were asked to rank the varieties based on two variables: taste and color/texture.

Statistical analysis of the various parameters was performed by either mixed model ANOVA, with block as a random factor, or one-way ANOVA. Fisher's LSD was calculated to describe differences between varietal means ($\alpha = 0.05$). Least significant difference values cannot meaningfully be reported for transformed data, so where data transformation was necessary to homogenize variances, significant differences between groups are reported using letter groups.

RESULTS

Growing Conditions

The 2008 growing season was characterized by extreme drought, with only 6.41 inches of precipitation occurring from the first of the year until trial harvest (Fig. 1). Of this amount, 5.43 in. fell over the period from May 14 to August 29. Average growing season temperatures were below normal by 1°F in May and 2°F in June, while average temperatures were 4° and 3° above average in July and August (Fig. 2). These higher average temperatures, which were illustrated by the fact that the temperature exceeded 90°F on 24 days of the season, combined with the extremely dry conditions, imposed severe stress on crops later in the season.

Carrots

General varietal characteristics of the types grown in this study are as follows: Hercules is a mid-season carrot with thick, tapered roots, Napoli is a Nantes type with blunt roots of average length, and

Nectar a full-season carrot similar to Negovia, but with slightly longer tapering roots sometimes grown for processing. Nelson is a commonly grown Nantes type that possesses short, blunt roots and is often harvested as a baby. Mokum is another early season carrot, while Sugarsnax 54 is a full-season carrot that produces long, slender roots.

Carrot yields were very low due to extreme drought (Table 2). The supplementary water applied undoubtedly improved yield to some extent, but not to a level that could be considered commercially competitive. Yields in the current trial ranged from 5191 kg/ha for Sugarsnax 54 to 8017 kg/ha for Hercules, while United States average commercial carrot yields in 2008 averaged approximately 15,000 kg/ha for fresh and 23,000 kg/ha for processing carrots (NASS). Overall, no significant differences in yield between varieties were observable, although Hercules and Napoli performed substantially better than the other four varieties, indicating some resistance to the dry conditions.

Significant differences in root length and diameter were observed between varieties. Sugarsnax 54 possessed the longest roots, with an average length of 17.8 cm. This is to be expected as this variety is known for its long roots. In fact, the varietal standard length of Sugarsnax 54 is 22 to 23 cm. Hercules, Napoli and Nectar had intermediate lengths, while Nelson and Mokum had the shorter observed lengths, averaging 12.5 and 13.7 cm, respectively. Hercules had the thickest roots, with diameter averaging 3.1 cm, Napoli and Nectar were intermediate, and Sugarsnax 54, Mokum and Nelson had the smallest diameters.

In terms of visual rankings, Hercules consistently ranked the highest and Sugarsnax 54 the lowest, although significant differences were not always observed between varieties. In the "condition of root" category, for instance, varieties did not differ significantly. In the other categories, however, Hercules appeal was demonstrated. In the "uniformity" category, Mokum and Nectar joined Hercules in having the most consist root structure, while in the "true to type" category Napoli, along with Hercules, had the highest ranking. In terms of the "visual appeal" and "size" categories, Hercules, Napoli, Nectar and Mokum had the highest rankings. Other than Sugarsnax 54, Nelson also consistently ranked poorly, and whereas Sugarsnax 54 tended to be branched, irregular and spindly, Nelson tended to be the most diminutive and least robust variety in the trial.

Taste tests did not indicate a distinct preference for any one variety, although Napoli ranked highest and Sugarsnax 54 the lowest. Analogously, in the color/texture category no clear winner emerged, although in this category Napoli again ranked highest and Nelson the lowest.

These results indicate that Hercules and Napoli may have some potential for production in the region, given their relatively high yield, visual ranking scores, and in the case of Napoli, taste preference. Sugarsnax 54, on the other hand, was a uniformly poor performer in all categories.

Potatoes

Of the five varieties screened in this study, Gold Rush is an early, white-fleshed russet type, while Red Gold has a thinner reddish skin, yellow flesh and is often used as a new potato. Yukon Gold possesses golden flesh and the waxier skin of a boiler. Superior is medium maturing white and Russian Banana is a specialty potato that produces many small, ellipsoid tubers which possess a thin waxy skin that withstands boiling.

Potato yields were similar (approximately 10 to 13,000 lb/ac) for all varieties except Russian Banana, which differed significantly from all other varieties and yielded only 1357 lb/ac (Table 3). The low yields of this variety are likely due in some part to its late flowering date, indicating that a longer season may be required for this variety than can be expected in western North Dakota. Average flowering dates for the other varieties ranged from July 3 for Superior to July 17 for Red Gold.

Photosynthetically active radiation below the potato leaf canopy did not differ between varieties (Fig. 3). Above canopy PAR, however, was always significantly greater than below, while overall PAR did not differ below or above canopy over the three dates.

Volumetric soil water content under potatoes did not differ between varieties at either depth on any date, but soil moisture under all varieties was significantly greater at the 19 in. depth than at the 3 in. depth on every date (Fig. 4). Interestingly, overall soil moisture remained consistent over all three dates at both depths, with values between 20 and 25% at the 3 in. depth and between 36 and 38% at the 19 in. depth. This indicates that no significant decline in water content occurred as the season progressed, even though extremely dry conditions were extent. This is not an entirely surprising observation at the 19 in. depth, given the relative resistance of the lower soil profiles to moisture depletion, but the fact that moisture remained consistent at a 3 in. depth is unexpected. Although soil samples were not taken as part of this study, it can be presumed that soil physical properties had much to do with this phenomenon.

A soils capacity for water storage is influenced by its structure and organic matter content.

Generally, a sandy, coarser textured soil has larger, more continuous soil pores and therefore a higher hydraulic conductivity. This translates into a diminished water holding capacity compared with finer textured soils. However, good soil structure and the presence of water stable aggregates can aid in soil water retention by providing a large amount of total pore space while concurrently slowing downward water movement and remaining resistant to erosion. Aggregate stability, in turn, is directly related to soil organic matter content (Brady and Weil, 1999). Soil organic matter is extremely important to water holding capacity in soil not only because it enhances aggregate stability, but also because it directly absorbs and stores water. While the soil at this location is relatively coarse textured, moisture content was maintained at approximately 20-25% at the 3 in. depth late into the season, translating to approximately 1/4 to 1/3 in. of available water according to government estimates (NRCS). The retention of this amount of water could very well be due to the positive effects of substantial organic matter content in the upper soil horizons as a result of historic no-till management. While the specific depth to which the potatoes were able to access water was not determined, it can be assumed that the ability of the upper soil profile to retain water was integral in guarding against permanent wilting in the potato crop. Furthermore, water retention under potatoes was also surely enhanced to some degree by the reduced light penetration through the crop canopy, as indicated by the significantly lower PAR observations below the canopy as opposed to above.

Russian Banana was somewhat susceptible to insect pest damage, presumably leafhopper, while no other varieties sustained any insect damage. Verticillium was responsible for the death of two Red Gold plants, but did not spread to neighboring plants. The source of the infection was assumed to be the seed.

The taste test indicated no preference for any particular variety, although Red Gold ranked the highest and Superior and Gold Rush the lowest. In terms of texture and color, Red Gold and Gold Rush ranked the highest and Superior the lowest, although no statistically significant difference in scores was discernable.

Sweet Corn

Eight sweet corn varieties were included in this trial. The Xtra Tender varieties are supersweet (*sh2*) types, while all other are sugary enhanced (*se*). As for maturity, Spring Treat is an early season variety, Sugar Pearl, Luscious and Xtra Tender 272A are mid-season varieties and the remainders are generally recognized to be full-season varieties.

Of the three vegetable crops grown in 2008, sweet corn suffered the most from the dry conditions. Early season vigor ratings were most favorable for Spring Treat (Table 4). Xtra Tender 378A followed Spring Treat in the rankings, which is somewhat surprising considering the tendency of sh2 varieties for reduced vigor in cooler soils. Luscious and Xtra Tender 277A, on the other hand, received the lowest scores. Interestingly, even though Luscious received a low early season vigor rating, it had the second earliest average date of tasseling, July 30, with only Spring Treat having an earlier tasseling date, July 24.

Sweet corn yields were very low. Sugar Pearl had the highest overall yields, averaging 3543 kg/ha, while Brocade and Xtra Tender 378A and 277A had the lowest yields. Additionally, actual marketable yield was markedly reduced in all varieties due mainly to arrested kernel development and uneven fill. On average, only about 25 to 30% of harvested ears were deemed of market quality, with Sugar Pearl producing the highest number of marketable ears, at 2133 per acre. Although large variability did not allow for any statistically significant differences to be observed in number of marketable ears, the variety producing the next greatest number was Xtra Tender 275A, with 960 ears/acre. One variety, Brocade, produced ears deemed marketable at all.

Given the dry conditions, plant heights of all varieties were low, with Sugar Pearl producing the tallest plants at 111 cm, although Luscious, Brocade and Xtra Tender 275A did not differ significantly in height from Sugar Pearl. Spring Treat was the shortest variety, with plants averaging only 78.1 cm tall.

Ear lengths were relatively uniform between varieties, averaging 18.1 cm, except for Spring Treat, which had significantly shorter cobs, measuring only 14.1 cm on average. In terms of ear width, Luscious produced the thickest ears, averaging 4.4 cm, while Brocade, Spring Treat, Sugar Pearl and Xtra Tender 277A produced the lowest average ear widths, averaging between 3.6 and 3.8 cm. Xtra Tender 277A and 378A had the greatest number of kernel rows/ear with 17. Spring Treat had the lowest with only 10. In the case of Spring Treat, and to a lesser extent in the other varieties, many ears contained unfertilized or aborted kernels and high variability in the fill pattern within the ear. Number of kernel rows is highly dependent on climatic and fertility conditions prior to and during silking, while stressful conditions later in the season can lead to aborted and unfilled kernels. It is assumed that the extremely variable kernel fill (and reduced ear length in Spring Treat) was attributable to the dry conditions in 2008.

CONCLUSION

Sweet corn was the most negatively impacted crop, but one variety, Sugar Pearl, did stand out as having relatively greater resistance to drought, even though its early season vigor was somewhat impaired. Sugar Pearl produced substantially more marketable ears than any other variety, although still yielding well below what could be considered economically viable. Nonetheless, this variety has been identified as having some potential for region and will be screened further in future years, as will the other varieties involved.

The other two vegetables screened, carrots and potatoes performed somewhat better overall than sweet corn. These vegetables are root or tuberous crops, which may have spared them somewhat from the most extreme effects of the drought. Still, yields were low in both crops. Carrots received minimal supplemental water, which undoubtedly boosted yields, but not to the level of average commercial yields. The Hercules carrot had the highest yield, although not significantly different from any other, and consistently ranked high in the visually assessed categories. Napoli also had a relatively favorable yield and performed adequately in the visual ranking, although uniformity seemed to be a slight issue for this variety. This variety also garnered the highest ratings in the taste test, although again, no statistical differences could be discern between varieties. The performance of these two varieties, Hercules and Napoli, indicate that they may have some drought resistance and therefore potential for the region. These varieties will be screened further to assess long term performance. The Sugarsnax 54 variety, on the other hand, stood out for its poor performance, in terms of yield, visual qualities and taste.

As stated, potato yields were low, although no plants succumbed to drought or heat stress, indicating that sufficient water was retained in the soil to allow for normal development, a conclusion further substantiated by soil moisture measurements. Superior, the earliest flowering variety, had the highest yield (although not significantly greater than any other), but ranked low in the taste test. On the other hand, the second highest yielding variety, Red Gold, performed well on the taste test, illustrating potential interest from consumers.

As stated several times previously, the biggest factor affecting vegetable performance in 2008 was the extremely dry conditions. Yields of all crops suffered greatly, but nonetheless, the data obtained proved useful in assessing the response of the utilized varieties to extreme climatic conditions. One way to alleviate some water and drought stress in the future may include experimenting with mulches or no-till seeding methods, both which are known to increase water infiltration and reduce evaporation from the soil surface. Overall, the extension of these trials into future years will provide further insight into the best variety choices for the region, and hopefully spur interest in vegetable production in the region, whether for personal use or for commercial applications.

Table 1. Vegetable crop varieties used in the experiment.

Sweet Corn	Carrots	Potatoes
Brocade	Hercules	Gold Rush
Luscious	Mokum	Red Gold
Spring Treat	Napoli	Russian Banana
Sugar Pearl	Nectar	Superior
Xtra Tender 272A	Nelson	Yukon Gold
Xtra Tender 275A	Sugarsnax 54	
Xtra Tender 277A		
Xtra Tender 378A		

Table 2. Characteristics of the six carrot varieties included in the present study.

Variety	Length	Diameter	Yield	Visual Rankings†					Taste Test	
				Condition of root	Uniformity	True to Type	Visual Appeal	Size	Taste	Texture/Color
	——— cm ———		kg/ha							
Hercules	14.4	3.1	8017	2.5	2.3	1.8	2.3	2.5	3.00	3.50
Napoli	15.6	2.6	7688	3.1	4.1	2.9	2.8	3.0	2.00	2.30
Nelson	12.5	1.8	5448	3.9	3.9	3.9	3.8	4.5	4.00	4.50
Nectar	15.4	2.4	5356	4.0	3.4	3.6	3.0	3.0	3.75	3.80
Mokum	13.7	1.9	5219	3.1	2.4	3.6	3.6	3.0	3.80	3.30
Sugarsnax 54	17.8	2.1	5191	4.4	5.0	4.9	5.6	5.0	4.50	3.80
Mean	14.9	2.3	6153	3.5	3.5	3.4	3.5	3.5	3.51	3.53
CV (%)	29.2	33.1	38	49.3	49.3	49.1	49.3	28.6	49.79	49.79
LSD ($\alpha = 0.05$)	1.8	0.3	NS	NS	1.5	1.5	1.4	2.0	NS	NS
P	0.0001	0.0001	0.1460	0.2590	0.0048	0.0040	0.0014	0.0121	0.433	0.6504

†Visual and taste test rankings are relative, with 1 being the highest ranking and 6 being the lowest.

Table 3. Characteristics of the five potato varieties included in the present study.

			Taste Test†	
Variety	1st flower	Yield lb/ac	Taste	Texture/Color
Superior	July 3	12770	3.50	4.25
Red Gold	July 17	12145	2.50	2.25
Gold Rush	July 10	10896	3.50	2.25
Yukon Gold	July 14	10078	2.75	3.00
Russian Banana	July 29	1357	2.75	3.25
Mean	July 16	7063	3.13	3.75
CV (%)	5	58	48.37	48.37
LSD ($\alpha = 0.05$)		3967	NS	NS
P		0.0001	0.8334	0.2745

†Taste test rankings are relative, with 1 being the highest ranking and 6 being the lowest.

Table 4. Characteristics of the eight sweet corn varieties included in the present study.

Variety	Vigor†	Tassle Date	Ears	Marketable Ears	Yield‡	Plant Height	Ear Length	Ear Diameter	Kernel Rows
			——— no./ac ———		kg/ha	——— cm ———			
Spring Treat	0.75	July 24	5733	751	1961b	78c	14.1b	3.6c	10d
Xtra Tender 378A	0.25	Aug 5	1445	285	788cd	102b	18.7a	4.0ab	17a
Xtra Tender 275A	-0.25	Aug 4	2942	960	1619bc	106ab	17.9a	4.1a	16b
Sugar Pearl	-0.75	July 31	5463	2133	3543a	111a	18.4a	3.8bc	15c
Xtra Tender 272A	-0.75	Aug 2	2153	680	1272bc	93b	16.6a	4.1a	16b
Brocade	-0.75	Aug 1	846	0	582cd	109a	18.9a	3.8bc	14c
Xtra Tender 277A	-1.00	Aug 4	603	490	417d	98b	18.9a	3.7bc	17a
Luscious	-1.00	July 30	2541	777	1719bc	105ab	17.2a	4.4a	16b
Mean	-0.44	1-Aug	2716	757	1488	100	18	4	15
CV (%)	173.56	5	92	104	93.00	12.9	12.0	10.6	15
LSD (α = 0.05)	0.76	–	2769	NS	–	–	–	–	–
P	0.0004	–	0.0045	0.0985	0.0087	0.0005	0.0011	0.0503	0.0001

†Vigor ratings are on a scale of -1 (below average) to +1 (above average).

‡Where data transformations were necessary LSD is not reported. Values within each column followed by the same letter do not differ significantly when α = 0.05.

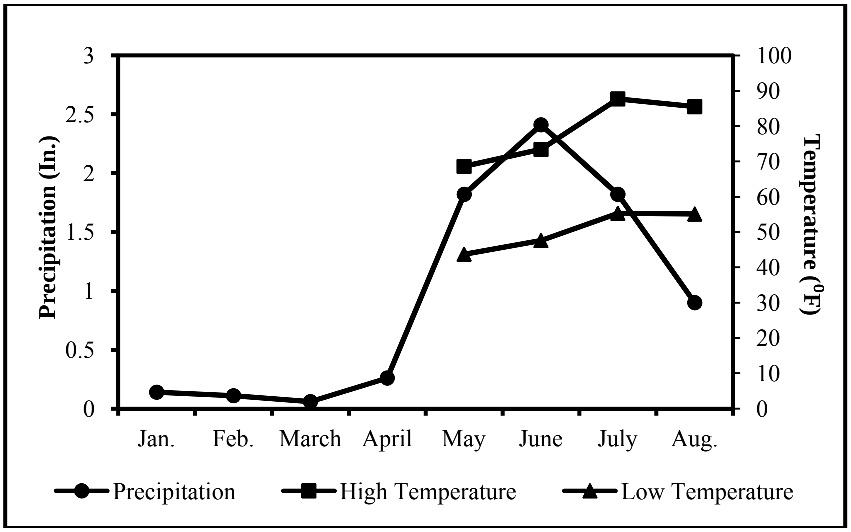

Figure 1. Average monthly precipitation and high and low temperatures for 2008.

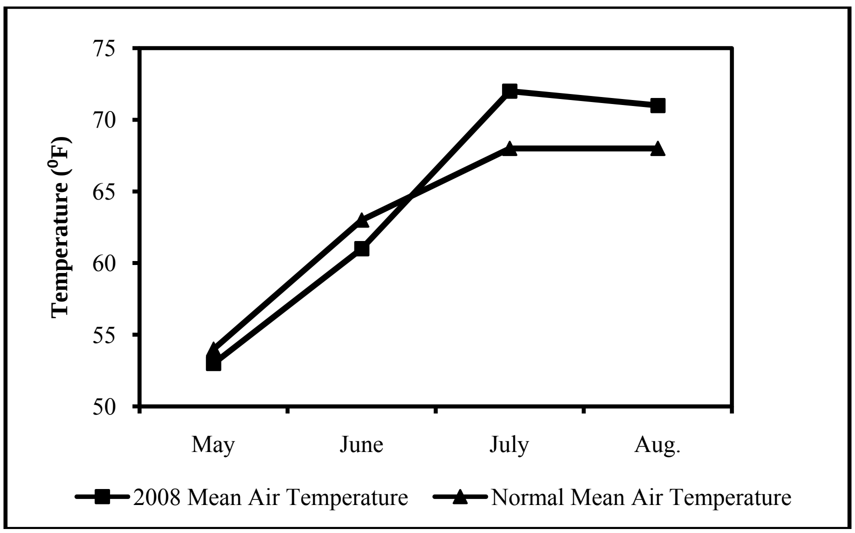

Figure 2. Mean monthly air temperatures for the 2008 growing season and annual averages for the period.

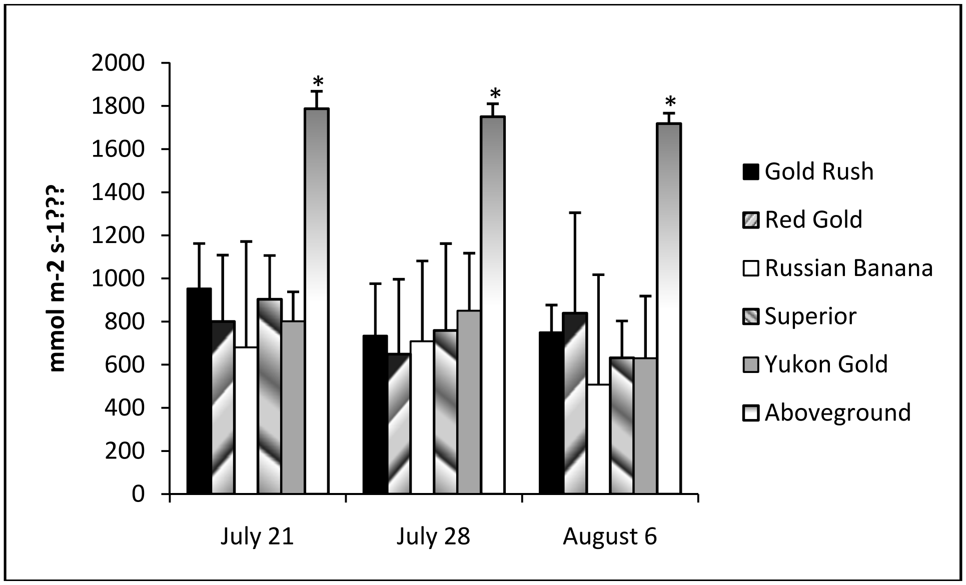

Figure 3. Photosynthetically active radiation as measured in potatoes on the three dates indicated. Asterisks denote significantly great above canopy PAR compared to all others on each date.

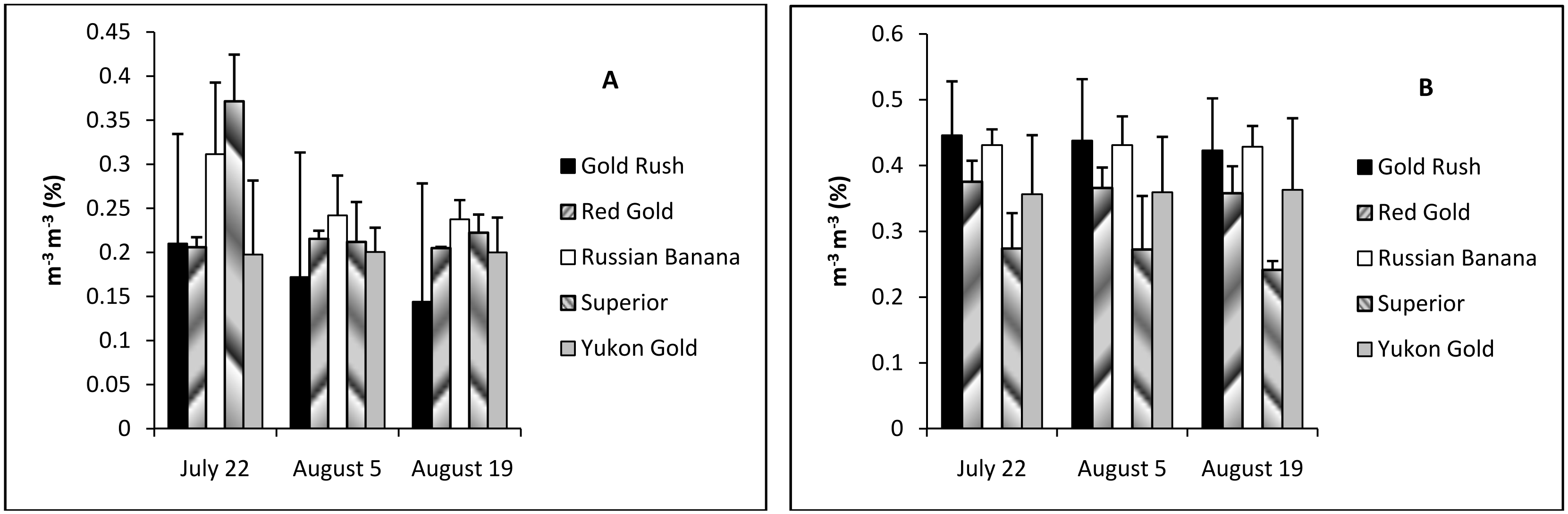

Figure 4. Volumetric water content at the (A) 3 inch and (B) 19 inch depth as measured in potatoes on the three dates indicated.

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