Increasing Cultivar Diversity of Processing Tomato under Large Scale Organic Production in California

Barrios Masias, F.[1], & Jackson, L.[2]

Key words: cultivar mixtures, plasticity, interaction, cover crop

Abstract

At an organic farm in California, higher plant diversity was hypothesized to enhance ecosystem functions and services. Plant diversity was manipulated temporally and spatially: mustard cover crop vs. no cover crop (fallow) in winter, and mixtures with one (farmer's best choice), three, or five processing tomato cultivars in summer. Soil N, soil microbial biomass, crop nutrient uptake, canopy light interception, disease, GHG emissions and biomass were measured. Results show that the mustard cover crop reduced soil nitrate (NO_3^-) in winter and also during the tomato crop, which was associated with decreased growth and canopy development. All cultivar mixtures had fairly similar yield and shoot biomass. The 'choice cultivar' (i.e. farmer's best choice) showed plasticity depending on the mixture, tending to have higher biomass production in mixtures. This study shows the complexity of cultivar-mixture interactions. To achieve the greatest benefit for ecosystem functions in organic farming, mixtures require greater understanding of cultivar plasticity and phenological and physiological trait diversity.

Introduction

Cultivar mixtures have been studied primarily for increasing yields (Burton et al., 1992) and disease control (Mundt, 2002), but other ecological processes have not been adequately evaluated. Cultivar mixtures may potentially provide a strong benefit for ecosystem functions in organic systems because of their limited management options and dependence on on-farm resources. Interaction among cultivars, and the effects of surrounding environment, may stimulate genotypic responses that could maximize the potential performance of a cultivar.

Mixtures are increasingly important in the framework of sustainable agriculture. Examples include rice in China (Meung et al., 2003), winter wheat in USA (Gallandt et al., 2001), and barley in the German Democratic Republic (Finckh et al., 2000). Even so, difficulties in managing cultivar mixtures can often be overestimated. Cultivar selection for mixtures depends on characteristics such agronomic compatibility, genotypic diversity (Mundt, 2002), high yields, and marketability. The number of genotypes in a cultivar mixture tends to be three (Mundt, 2002).

The central question of this study was: Why choose a cultivar mixture instead of a monoculture in an organic agroecosystem? It was hypothesized that increasing plant diversity may increase ecosystem functioning. A diverse tomato community may better use available nutrients, water and light resources. Some mixtures may perform

[1] Department of Land, Air and Water Resources, University of California, Davis, One Shields Ave., Davis, CA 95616, USA, E-Mail fbarrios[a]ucdavis.edu

[2] As above, E-Mail lejackson[a]ucdavis.edu, Internet http://groups.ucanr.org/jacksonlab/

similarly in different environments (yield stability). Cultivar differences in allocation and growth, including plasticity responses in different mixtures, may help to increase resource use and yield stability, and decrease N loss due to complementarities in root system development, depths, and N needs.

The main objectives of this study were: to measure the effects on phenotypic, nutrient uptake, and yield response of a ‘choice cultivar’ (i.e. farmer’s best choice) when interacting in three different tomato communities, and thus on yield stability; to assess the effects of tomato community composition on resource utilization and its response to the surrounding environment, i.e., disease pressure and abiotic stress, using indicator variables; and to examine, at the ecosystem level, the effects of soil N availability on tomato communities.

Materials and methods

Our study involved participatory research with a 14-year organic processing tomato grower at a 44 ha organic certified farm in Yolo County, California (California Certified Organic Farmers http://www.ccof.org/). His main commodities were processing tomatoes and oats as hay, as well as a fall/winter cover crop. Processing tomatoes were grown every other year on alternating fields using conventional tillage, and were furrow irrigated during the processing tomato crop, i.e., spring and summer season.

Two different sets of environmental conditions were established prior to tomato planting: winter fallow and mustard cover crop, i.e., main plot treatments of 16x9 m, each with 6 beds. Three cultivar mixtures as subplot treatments of 5x9 m with 6 beds utilized processing tomato cultivars that had the following characteristics: high yielding and currently marketable, grown commercially with similar amounts and timing of inputs, mid-maturity varieties, i.e., ~125 days from planting to harvest, and fruit quality that met industry standards. Subplot treatments consisted of the ‘choice cultivar’ grown by the farmer in the entire field (1 cv); a mixture of the 'choice cultivar' plus two more cultivars used by the same farmer on other of his fields (3 cv); and these three cultivars plus two more that were currently used by other organic growers in California for a total of 5 cultivars (5 cv). A completely randomized block design with a split-plot treatment structure was used. A total of eight blocks were established.

Soil sampling and measurements were as follows. Nitrate (NO_3^-) and ammonium (NH_4^+) by KCl extractions of field moist soil at three depths (0-15, 15-30 and 30-60 cm). Microbial biomass carbon (MBC) was analyzed for the 0-15 and 15-30 cm depths using the fumigation extraction method (Vance et al., 1987). Carbon dioxide (CO_2) and nitrous oxide (N_2O) gas emissions were sampled on the bed shoulder after irrigation events using closed, capped chambers for 30 min (Rolston, 1986). Biomass samplings for shoots and fruits of individual plants for the 'choice cultivar' and for the cultivar mixtures were done throughout the season. These samples were analyzed for N content by C/N combustion. Measurements of canopy light interception using a portable tube solarimeter with sensors for photosynthetically active radiation (PAR) and disease evaluation for *Sclerotium rolfsii* (Southern blight) were also performed intermittently.

Results

Yields were similar for all tomato cultivar treatments within each of the two winter treatments, with and without a cover crop. The vegetative growth of all cultivar mixtures performed better in winter fallow plots, e.g., canopy light interception and aboveground biomass were higher. Total N uptake (g N m^{-2}) tended to be lower in the winter mustard plots, and did not differ between cultivar mixtures and the 'choice cultivar' (Table 1). Plants lost to disease tended to be higher in winter mustard plots.

The ‘choice cultivar' (farmer’s best choice) had higher biomass productivity when in mixtures of 3 or 5 cultivars, at mid-season and in the N-limited winter mustard plots, e.g., its shoot and fruit biomass was highest in the 3 cv mixture at 75 DAP in the winter mustard plots. By the end of the season, however, similar yields for harvestable tomatoes were found in the 'choice cultivar' in the three tomato mixtures.

Inorganic N was more available in winter fallow plots. The winter mustard cover crop decreased N availability from prior to cover crop incorporation through tomato harvest, and it generally increased soil microbial biomass (significant only at 7 days after planting (DAP), suggesting higher microbial activity. CO_2 and N_2O emissions were generally similar in the tomato cultivar treatments, but CO_2 emissions were initially higher in the winter mustard plots. CO_2 emissions in the fallow plot were higher for the monoculture in the last two spot samplings, and N_2O emissions were variable with a tendency of the 5 cv mixture to be higher in winter fallow plots.

Table 1. Light interception, aboveground biomass, harvest index and N uptake at early and mid crop season and harvest time for processing tomato mixtures in California. Data shown for cover crop mainplots and cultivar mixtures (cv).

DAP^	Variables	Cover crop treatment Fallow *	Mustard	Winter fallow plots 1cv	3cv	5cv	Winter mustard plots 1cv	3cv	5cv
35 DAP	PAR** intercepted (%)	19.54 ± 1.05 a	15.27 ± 0.94 b	21.56 ± 1.20	18.51 ± 1.85	18.55 ± 2.25	15.47 ± 1.89	14.88 ± 1.50	15.47 ± 1.68
69 DAP	PAR intercepted (%)	45.64 ± 1.04 a	38.52 ± 1.34 b	46.07 ± 1.43	45.63 ± 2.18	45.20 ± 1.96	38.75 ± 1.54	39.86 ± 2.65	36.93 ± 2.76
95 DAP	PAR intercepted (%)	46.83 ± 1.18 a	42.57 ± 1.26 b	48.05 ± 2.61	46.38 ± 1.61	46.07 ± 2.00	45.05 ± 1.88 x	39.99 ± 2.23 y	42.67 ± 2.29 xy
39 DAP	Shoot biomass (g m^{-2})	70.43 ± 6.82	53.83 ± 4.71	71.61 ± 9.80	73.98 ± 11.60	65.69 ± 16.41	68.12 ± 3.76 x	48.97 ± 8.49 xy	44.39 ± 7.21 y
75 DAP	Shoot biomass (g m^{-2})	245.68 ± 17.42	275.38 ± 19.74	251.00 ± 21.15	249.80 ± 42.01	236.30 ± 32.86	222.11 ± 35.10 x	323.86 ± 27.00 y	280.17 ± 24.28 xy
111 DAP	Shoot biomass (g m^{-2})	293.62 ± 9.25	273.75 ± 13.16	274.04 ± 17.37	292.02 ± 15.04	310.55 ± 14.33	302.44 ± 29.23	262.06 ± 21.95	256.77 ± 13.88
75 DAP	Fruit biomass (g m^{-2})	122.20 ± 12.55	126.31 ± 13.78	135.57 ± 22.62	123.43 ± 16.15	107.59 ± 28.77	99.96 ± 23.15 x	163.04 ± 28.14 y	115.93 ± 6.60 xy
111 DAP	Total fruit (g m^{-2})	351.86 ± 15.36 a	251.94 ± 15.12 b	365.84 ± 29.75	351.84 ± 23.77	337.89 ± 28.65	269.49 ± 35.61	233.99 ± 18.64	252.33 ± 23.40
111 DAP	Harvestable fruit (g m^{-2})	234.45 ± 14.75 a	161.98 ± 15.56 b	240.75 ± 26.06	232.80 ± 26.90	229.81 ± 27.06	185.68 ± 38.69	146.77 ± 20.08	153.49 ± 19.03
111 DAP	Harvest index	0.36 ± 0.02 a	0.30 ± 0.01 b	0.37 ± 0.03	0.37 ± 0.02	0.35 ± 0.03	0.31 ± 0.04	0.29 ± 0.02	0.30 ± 0.02
111 DAP	Aboveground N (g N m^{-2})	11.53 ± 0.38	9.57 ± 0.38	11.56 ± 0.71	11.86 ± 0.61	11.19 ± 0.81	9.83 ± 0.70	9.06 ± 0.83	9.82 ± 0.52

^ Days after transplanting; ** PAR, photosynthetically active radiation; * Different letters indicate statistical differences using the Tukey test.

Discussion

Cultivar mixtures showed little difference compared to the 'choice cultivar' alone, in terms of any of the variables that were measured: yield, vegetative biomass, canopy light interception, and disease. These results imply that the cultivars are fairly similar in terms of response to abiotic and biotic environmental conditions. In fact, the breeding lines for processing tomatoes in California are from the same genetic stocks, and have specific genes that adapt them to the machine harvest of processing tomatoes, e.g., similarly early flowering times, determinate growth, and compact canopies (Jones et al., 2007). Breeding programs in California have developed cultivars that are high performers as monocultures, and thus have selected the highest yielding cultivar rather than the best cultivar mixture. Results suggest potential benefits if mixtures are formed with cultivars that complement and maximize their performance when interacting with each other, e.g., the grower’s ‘choice cultivar’ showed early benefits in vegetative growth in mixtures. Overall mixture productivity might increase if environmental stress had been greater.

The winter mustard cover crop did not benefit tomato production and decreased N availability, probably because of the high microbial activity that immobilized N early in the tomato growing season. While N leaching potential was reduced, this came at the cost of lowered productivity. Also the late, rainy spring forced the grower to delay the incorporation of the winter mustard crop, and the maturity of the plants may have been a factor in increasing N immobilization potential.

Conclusions

Cultivar interactions, their complementarity or competitiveness in a mixture, may potentially provide benefits for ecosystem functions on organic farms. Cultivars of such a mixture would likely perform better in a mixture than in monoculture. In such a situation, cultivars would be expected to have greater trait variation than is presently found in mainstream California processing tomatoes. In addition, phenological and physiological trait diversity of a cultivar mixture must be incorporated into management practices, e.g., nutrient management, irrigation, and harvest time. This study shows the difficulty of grouping together a set of cultivars that as a mixture can enhance ecosystem functions and benefit organic systems. Improving mixtures for multifunctional benefits will require better understanding of functional traits (Balvanera et al., 2006), and testing many combinations of diverse assemblages, so that the highest yielding mixture can be selected in comparison to the highest yielding monoculture (Cardinale et al., 2006).

Acknowledgments

This research was supported by USDA OERI grant 2004-51106-02242 to L. Jackson.

References

Balvanera, P., A.B. Pfisterer, N. Buchmann, J.S. He, T. Nakashizuka, D. Raffaelli, and B. Schmid. 2006. Quantifying the evidence for biodiversity effects on ecosystem functioning and services. Ecol. Lett. 9:1146-1156.

Burton, J.W., M.O. Fountain, X. Meng, and T.E.J. Carter. 1992. Interplanting early- and late-maturing soybean cultivars in alternating strips. J. Prod. Agric. 5:100-103.

Cardinale, B.J., D.S. Srivastava, J.E. Duffy, J.P. Wright, A.L. Downing, M. Sankaran, and C. Jouseau. 2006. Effects of biodiversity on the functioning of trophic groups and ecosystems. Nature 443:989-992.

Finckh, M.R., E.S. Gacek, H. Goyeau, C. Lannou, U. Merz, C.C. Mundt, L. Munk, J. Nadziak, A.C. Newton, C. de Vallavieille-Pope, and M.S. Wolfe. 2000. Cereal variety and species mixtures in practice, with emphasis on disease resistance. Agronomie 20:813-837.

Gallandt, E.R., S.M. Dofing, P.E. Reisenauer, and E. Donaldson. 2001. Diallel analysis of cultivar mixtures in winter wheat. Crop Sci. 41:792-796.

Jones, C.M., C.M. Rick, D. Adams, J. Jernstedt, and R.T. Chetelat. 2007. Genealogy and fine mapping of obscuravenosa, a gene affecting the distribution of chloroplasts in leaf veins, and evidence of selection during breeding of tomatoes (*Lycopersicon esculentum*; Solanaceae). Am. J. Bot. 94:000-000.

Meung, H., Y.Y. Zhu, I. Revilla-Molina, J.X. Fan, H.R. Chen, I. Pangga, C.V. Cruz, and T.W. Mew. 2003. Using genetic diversity to achieve sustainable rice disease management. Plant Dis. 87:1156-1169.

Mundt, C.C. 2002. Use of multiline cultivars and cultivar mixtures for disease management, p. 381-410 Annual Review of Phytopathology. Volume 40.

Rolston, D.E. 1986. Gas flux, p. 1103-1119, *In* A. Klute, ed. Methods of Soil Analysis Part I. Physical and Mineralogical Methods., 2nd ed. ASA and SSSA.

Vance, E.D., P.C. Brookes, and D.S. Jenkinson. 1987. An extraction method for measuring soil microbial biomass-C. Soil Biol. Biochem. 19:703-707.