United States Department of Agriculture

FINAL STUDY REPORT (September 2022)
Hoolehua PMC
Hoolehua, Hawaii

An Evaluation of Warm-Season Cover Crops in Hawaii, 2020-2021

Richard Ogoshi, David Duvauchelle, John Colon

ABSTRACT

Cover crop is a fast-growing conservation practice, but the availability of information on variety or species adaptation to Hawaii and the Pacific Islands is limited. Seventeen varieties of 13 species, pigeonpea (*Cajanus cajun*), sunn hemp (*Crotalaria juncea*), soybean (*Glycine max*), lablab (*Lablab purpureus*), white sweet clover (*Melilotus alba*), yellow blossom sweet clover (*Melilotus officinalis*), alfalfa (*Mendicago sativa*), pearl millet (*Pennisetum glaucum*), mung bean (*Vigna radiata*), cowpea (*Vigna unguiculata*), forage sorghum (*Sorghum bicolor*), sudangrass (*Sorghum bicolor* ssp. *Drummondii*), sorghum-sudan (*Sorghum bicolor x Sorghum bicolor* var. *sudanense*) were planted at the Hoolehua Plant Materials Center, Hoolehua, Hawaii, in July 2020 and 2021. Recorded data included emergence rating, dates of first and peak bloom, plant height, canopy cover, insect and disease damage rating, and biomass yield. Cover crop varieties 'Growers Choice' sorghum, 'Honey Graze' sorghum-sudan, 'Piper' sudangrass, 'Rongai' lablab, and 'Tropic Sun' sunn hemp displayed quick canopy cover and high biomass yield, so they are expected to suppress weeds well. The wide range of growth vegetative growth duration exhibited by varieties 'Growers Choice' sorghum, 'Honey Graze' sorghum-sudan, 'Piper' sudangrass, 'Rongai' lablab, and 'Tropic Sun' sunn hemp are expected to provide growers flexibility to schedule a cover crop between main crops. Compatible species for cover crop mixes were identified based on height and peak bloom date. 'Large Lad' soybean and 'Georgia Two' pigeonpea are not recommended as cover crops because of heavy bird predation observed in both years. The adaptation data developed in this study provided the expected performance of these varieties as cover crops in Hawaii and the Pacific Islands.

INTRODUCTION

Farmers implement a variety of different conservation practices to improve their cropping system and utilizing cover crops is amongst the most important. Planting fallow land with a cover crop imparts many benefits. Covering the soil with a cover crop protects against wind and rain erosion; decomposition of root and shoot residue increases soil carbon that improves soil physical and chemical properties such as aggregate stability, water holding capacity, infiltration rate and cation exchange capacity; biological nitrogen fixation and decomposition of cover crop residue improves soil fertility; root and shoot residue provide a feed source for soil micro- and macro-organisms that support soil function; uptake of excess soil nutrients prevents nutrient movement to off-site locations; shade from the cover crop canopy and residue layer suppress weeds; and cover crop flowers attract and provide feed for pollinator and beneficial insects (Sullivan, 2003; Treadwell et al., 2012a). A cover crop species commonly excels at providing one or two of these benefits. The many benefits make cover cropping an attractive conservation practice.

R. Ogoshi, D. Duvauchelle, J. Colon, 4101 Maunaloa Hwy. Hoolehua, HI 96729, richard.ogoshi@usda.gov

The utilization of cover crops is growing rapidly in the United States. Cover crops on farmland increased from 10.3 million acres to 15.4 million acres between 2012 and 2017, a 50% jump in 5 years (Wallander et al., 2021). The fastest growth occurred in southeastern Iowa where soil organic matter is low or soil erosion is high; Texas where cotton and corn silage is harvested in mid- to late-summer allowing an earlier planting for cover crops; and Pennsylvania and Maryland where state and county programmatic incentives are promoted (Wallander et al., 2021). Adoption seems to be fastest where there is a critical resource problem to address, the practice can fit in the current cropping system, or there is technical and financial support.

Implementing cover crops for the first time by both new and seasoned producers can be challenging. At the farm level, there are several factors the producer should consider before incorporating a cover crop into their cropping system. According to Duncan (2017), Radovich (2010), and Sullivan (2003), these factors include, but are not limited to:

1) The selected cover crop addresses the producer’s objective.
2) The cover crop species is adapted to the farm location.
3) The cover crop fits the cropping system and does not interfere with the main crop.
4) The cost for cover crop seed, establishment, and termination is affordable
5) The equipment to manage cover crops is available.
6) The cover crop is not a host for insects and diseases that affect the main crop.
7) The cover crop is not invasive to the local environment.

Producers in Hawaii and the Pacific Islands Area enjoy a year-round growing season that allows them to harvest multiple crops from the same field in a single year. Of the limited cover crop research in Hawaii, much of it is based on fitting cover crops into the year-round production system and/or evaluating capacity to resist harmful insects and diseases. In a year-round, continuous cropping system, replacing a main crop with a cover crop would reduce revenue during that portion of the year when the cover crop is growing. The avoidance of revenue loss has been an overarching objective, researchers studied the effects of cover crops grown simultaneously with the main crop in Hawaii, known as strip-cropping. Cucumber and bitter melon were strip-cropped into cover crops sunn hemp (Crotalaria juncea) and marigold (Tagetes patula) (Manandhar et al., 2017), and cover crops were planted between rows of sugarcane or orchard trees (Evensen and Osgood, 1991; Evans et al., 1988). Furthermore, evaluating a cover crop’s potential to interrupt the life cycle of diseases and insects that are detrimental to the main crop has been of particular interest. For example, root-knot nematodes can severely reduce taro corm yield. Sipes and Arakaki (1997) found that seven out of 22 cover crop species planted prior to planting taro did not host root-knot nematode and did not reduce corm yield in the taro crop. Similar efforts have been made to screen cover crop species that host nematode for other crops such as zucchini (Waisen et al., 2022; Wang et al., 2002).

Information on the growth characteristics and adaptability of cover crops is essential when selecting cover crops for a specific purpose. Cover crop species that produce biomass of 8000-12000 lb/acre dry weight effectively suppress weeds (Treadwell et al., 2012a). Cover crops that develop closed canopies faster prevent soil erosion from wind and rain earlier than those that do not (Sullivan, 2003; Treadwell et al., 2012a). Although there is a wealth of information on cover crop characteristics and adaptability, information that is specific to Hawaii and the Pacific Islands Area is limited and/or not readily available.

The objective of this study is to develop and summarize cover crop species characteristics for 17 varieties of 13 cover crop species in the Pacific Island area. The characteristics to be determined are emergence rating, disease and insect damage ratings, percent canopy cover and plant height at 28 days after planting (DAP) and at final evaluation either at the time of full bloom or 91 DAP whichever is earlier, date of first bloom and peak bloom, and biomass yield.

MATERIALS AND METHODS

The study was located at the Hoolehua Plant Materials Center (PMC), Hoolehua, Hawaii. The soil at the PMC is classified as a Holomua series (fine, kaolinitic, isohyperthermic Typic Eutrotorrox). Annual rainfall is 21 inches and mean annual air temperature is 73.5 °F.

Commercially available, warm season cover crops were planted on July 1, 2020, and July 21, 2021, following current seeding rate recommendations from the Natural Resources Conservation Service, U.S. Department of Agriculture (Table 1). Plots were planted using a Kincaid Precision Plot Seed Drill (Kincaid Equipment, Haven KS) with 7.5-inch row spacing. Plot size was 5 feet x 12 feet. Soil fertility was managed following soil test recommendations. In 2020, total fertilizer was broadcast at 60 lbs. N, 196 lbs. P, and 47 lbs. K per acre split into two applications on July 10 and August 7. In 2021, a total of 73 lbs. N, 95 lbs. P, and 60 lbs. K per acre was broadcast in two applications on August 4 and 20, 2021. Irrigation was applied with overhead sprinklers at a rate of 1.3 inches per week for the duration of the study. Weeds were managed by hand rogueing within each plot and mowing the aisles.

At 7 and 14 DAP, field emergence was estimated for each plot using a visual rating scale: 0 = poor (<25% germination), 1 = moderate (25-64% germination), 2 = good (65-85% germination), 3 = excellent (>85% germination). At 28 DAP and at peak bloom, plant height, canopy cover, and disease and insect damage were evaluated. The first bloom date for each plot was also recorded when at least 10% of the plot was flowering. Peak bloom date was recorded when 90% of the plot was in flower. Plant height was determined by taking the average of 3 random heights within each plot. Percent canopy cover was determined by taking a photo, looking down at the center of each plot, at shoulder height with the Canopeo App (Oklahoma State University, Stillwater, OK). The Canepeo App was able to provide a % of vegetative cover based on color differences between soil and vegetation. Disease and insect damage was estimated using a visual rating scale of 0-3, where 0 = no damage and 3 = severe damage. Additionally, biomass yield samples were taken at peak bloom. To measure biomass yield, a 10.8 ft^2 section was harvested from the interior rows of the plot. All vegetation within the sample area was cut down to the surface of the soil and weighed. A subsample approximately 200 g was then separated, weighed, and dried in a forced-draft oven at 60 °C. The weights of the subsamples were monitored until the weights had stabilized, about two to four days. The fresh and oven-dry subsample weights, and fresh plot sample weights were used to calculate the total dry-weight biomass production for each plot. Daily air temperature and rainfall were recorded on an automatic logger Model CR1000x (Campbell Scientific, Logan, UT). The weather station was located 3000 feet north of the experimental plot.

The experimental design was a randomized complete block with four replications. The treatments were 17 varieties of 13 cover crop species and randomly assigned within replications (Table 1). Means and standard deviations were calculated with Statistix 10 (Analytical Software, version 10.0) for all data except biomass. Biomass yield data were transformed with the form Ln(x+1) and variance analyzed as a combined year, randomized complete block (Gomez and Gomez, 1984). Data normality was assessed with the Shapiro Wilk test in Statistix 10 (Analytical Software, version 10.0, Tallahassee, FL). Statistically significant differences in biomass yield were determined by Tukey's Honest Significant Difference mean separation test at $P<0.05$ when the analysis of variance indicated significant treatment effects. Homogeneity of variances among years was determined with Levene's Test (NIST, 2012). Missing data was estimated according to procedures described by Gomez and Gomez (1984). No more than two data were missing of an independent variable in one year.

Table 1. Warm season cover crops planted in a 2-year trial at the USDA NRCS Hoolehua Plant Materials Center Hoolehua, Hawaii, 2020-2021

Common Name	Species	Cultivar	Seeding Rate lb/acre
cowpea	*Vigna unguiculata*	'Red Ripper'	60
cowpea	*Vigna unguiculata*	'Chinese Red'	60
cowpea	*Vigna unguiculata*	'Iron and Clay'	60
sun hemp	*Crotalaria juncea*	'Tropic Sun'	15
sun hemp	*Crotalaria juncea*	VNS	15
yellow blossom sweet clover	*Melilotus officinalis*	VNS	20
white sweet clover	*Melilotus alba*	'Hubam'	20
alfalfa	*Mendicago sativa*	VNS	20
mung bean	*Vigna radiata*	VNS	80
lablab	*Lablab purpureus*	'Rongai'	20
pearl millet	*Pennisetum glaucum*	'Leafy 22'	20
sorghum-sudan	*Sorghum bicolor x Sorghum bicolor var. sudanense*	'Honey Graze BMR'	10
forage sorghum	*Sorghum bicolor*	VNS	15
sudangrass	*Sorghum bicolor ssp. drummondii*	VNS	15
soybean	*Glycine max*	'Laredo'	40
soybean	*Glycine max*	'Large Lad'	40
pigeon pea	*Cajanus cajan*	'Georgia Two'	50

VNS variety not specified

RESULTS AND DISCUSSION

Growing conditions were suitable for the cover crop species in both years of the study. Average air temperature during the 91 days of growth was 78.6 and 77.4 °F in 2020 and 2021, respectively (Figure 1). Total rainfall in the same period was 0.97 and 1.18 inches in 2020 and 2021, respectively (Figure 1). A total of 17 inches of irrigation water was applied during each growth period in 2020 and 2021.

Heavy bird damage affected the plots with 'Large Lad' soybean and 'Georgia Two' pigeonpea. Approximately 90 to 95% of the plants were heavily damaged or missing. Birds tentatively identified as Red-crested cardinal (*Paroaria coronate*), francolin (*Francolinus pondicerianus* and/or *Pternistis erckelii*), Spotted dove (*Spilopelia chinensis*), and Zebra dove (*Geopelia striata*) were observed foraging in these plots. The bird damage was restricted to the soybean and pigeonpea plots despite the plots being randomized in the field. The data from these varieties of soybean and pigeonpea were not included in the statistical analyses and not presented in the results.

Cover crop characteristic data are presented as means over years. Temperature and rainfall data in 2021 and 2022 were similar (Figure 1) and presumed to affect cover crop growth and development similarly. Transformed biomass yield data was normal and variances between years were homogeneous at $p < .05$ (data not shown). The combined year analysis of variance of biomass yield showed no significant effects for 'Year' and 'Variety x Year' sources of variation (Table 2). The source of variation 'Variety' was highly significant and displayed in the tables below.

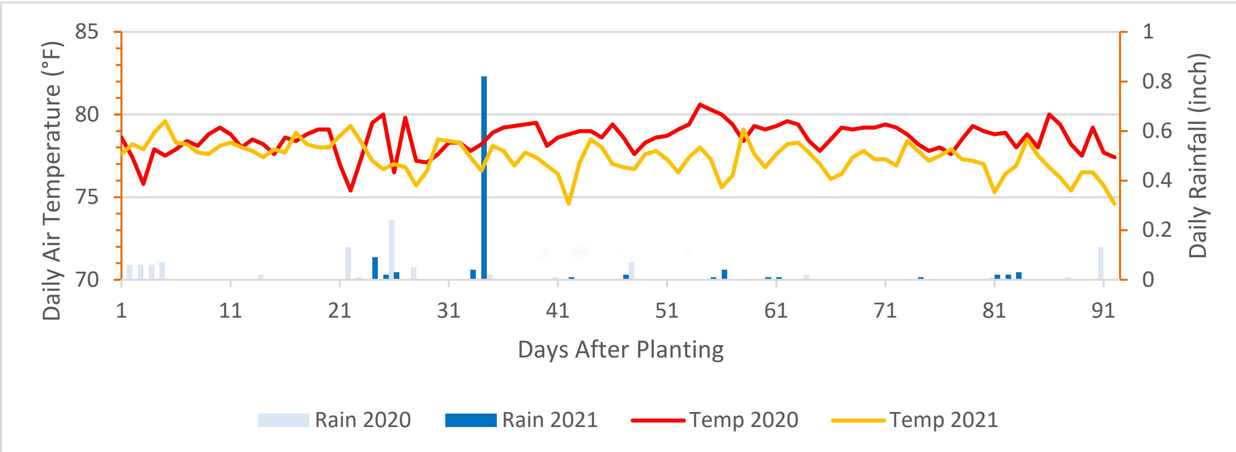

Figure 1. Daily air temperature and rainfall for 91 days following planting of cover crops on July 1, 2020, and July 21, 2021, at the Hoolehua Plant Materials Center, Hoolehua, Hawaii.

Table 2. Combined year analysis of variance for biomass yield, data transformed ln(x+1).

Source	df	MS	F-ratio
Year	1	0.0142	0.0331 ns
Rep (Year)	6	2.58	
Variety	14	27.9	10.0 **
Variety x Year	14	2.79	1.48 ns
Pooled Error	84	11.3	

ns not significant at $p < .05$
** significant at $p < .01$

Cowpea

All three cowpea varieties showed fair to good cover crop characteristics. 'Chinese Red' and 'Iron and Clay' emerged well, while 'Red Ripper' was fair (Table 3). Fast growth was evident in the canopy cover % at 28 DAP. Chinese Red, Iron and Clay, and Red Ripper had canopy cover of 79, 74, and 69%, respectively, at 28 DAP and increased to 89% or more at the full bloom stage (Table 4). The relatively quick cover is an important characteristic to control weeds and reduce soil erosion. First bloom was observed at 37 to 48 DAP and peak bloom at 6 to 11 days later (Table 5). The time from planting to peak bloom indicated the duration of cover before termination becomes necessary to prevent potential weed problem for the main crop. Cowpea reached peak bloom at 44 to 59 DAP, which is below the median among the species tested in this study (Table 5). Plant height at 28 DAP ranged from 34 to 42 cm and peak bloom height ranged from 53 to 80 cm (Table 6). The insect and damage ratings were light for Iron and Clay, Red Ripper, and Chinese Red (Table 7). Chinese Red and Iron and Clay had significantly greater biomass than 'Red Ripper', however all three varieties did not produce a biomass yield of 8000 to 12000 dry lb/acre, which is known to effectively suppress weeds for a subsequent main crop (Table 8; Treadwell et al., 2012a).

Table 3. Cowpea emergence ratings at 14 DAP, 2020 and 2021.

Cultivar	Mean	SD
Chinese Red	2.4	0.52
Iron and Clay	2.1	0.83
Red Ripper	1.8	0.71

SD standard deviation
Emergence ratings:0 = <25% (poor), 1 = 25 – 50 % (fair), 2 = 50-75% (good), 3 = >75% (excellent)

Table 4. Cowpea canopy cover %, 2020 and 2021.

	28 DAP		Peak Bloom	
Cultivar	Mean	SD	Mean	SD
Chinese Red	79	14	94	4.8
Iron and Clay	74	17	89	10
Red Ripper	69	19	92	3.9

SD standard deviation
DAP days after planting

Table 5. Cowpea bloom DAP, 2020 and 2021.

	First Bloom		Peak Bloom	
Cultivar	Mean	SD	Mean	SD
Chinese Red	39	1.9	46	1.0
Iron and Clay	48	7.9	59	3.5
Red Ripper	37	2.4	44	1.8

SD standard deviation
DAP days after planting

Table 6. Cowpea plant height (cm), 2020 and 2021.

	28 DAP		Peak Bloom	
Cultivar	Mean	SD	Mean	SD
Chinese Red	38	9.6	80	20
Iron and Clay	42	6.6	65	23
Red Ripper	34	6.9	53	11

DAP days after planting

Table 7. Cowpea insect and disease at peak bloom, 2020 and 2021.

	Insect		Disease	
Cultivar	Mean	SD	Mean	SD
Chinese Red	2.0	0.0	1.5	0.54
Iron and Clay	1.6	0.52	1.0	0.00
Red Ripper	1.5	0.54	1.0	0.00

SD standard deviation
Insect and disease ratings were based on a 0-3 scale: 0 = no damage, 3 = severe damage

Table 8. Cowpea biomass yield (dry lb/acre), 2020 and 2021.

Cultivar	Mean
Chinese Red	4591 a*
Iron and Clay	5725 a
Red Ripper	3567 b

*Means followed by different letters are significantly different at $P<0.05$

Sunn Hemp

Sunn hemp, particularly 'Tropic Sun', displayed many characteristics desired in a cover crop. Emergence of sunn hemp VNS (variety not specified) and Tropic Sun were close to excellent (Table 9) and produced ample canopy cover quickly at 28 DAP that persisted until peak bloom (Table 10). Both varieties were similar height at 28 DAP, 75 and 80 cm, but at peak bloom Tropic Sun was taller at 236 cm than sunn hemp VNS at 174 cm (Table 11). Sunn hemp VNS reached first and peak bloom earlier than Tropic Sun (Table 12). Both varieties showed little susceptibility to insects and disease (Table 13). Tropic Sun produced significantly more biomass than sunn hemp VNS. Tropic Sun produced 9406 dry lbs./acre biomass which is more than the 8000 dry lbs./acre that is expected to suppress weeds while sunn hemp VNS fell short at 5514 dry lbs./acre (Table 14; Treadwell et al., 2012a).

Table 9. Sunn hemp emergence rating at 14 DAP, 2020 and 2021.

Cultivar	Mean	SD
sunn hemp VNS	2.6	0.18
Tropic Sun	2.9	0.35

DAP days after planting
SD standard deviation
Emergence ratings scale: 0 = <25% (poor), 1 = 25 – 50 % (fair), 2 = 50-75% (good), 3 = >75% (excellent)

Table 10. Sunn hemp canopy cover %, 2020 and 2021.

	28 DAP		Peak Bloom	
Cultivar	Mean	SD	Mean	SD
sunn hemp VNS	86	11	90	8.8
Tropic Sun	90	9.0	94	4.0

DAP days after planting
SD standard deviation

Table 11. Sunn hemp plant height (cm) at 28 DAP and at final rating, 2020 and 2021.

	28 DAP		Peak Bloom	
Cultivar	Mean	SD	Mean	SD
sunn hemp VNS	75	9.4	174	28.4
'Tropic Sun'	80	13	236	21.2

DAP days after planting
SD standard deviation

Table 12. Sunn hemp bloom DAP, 2020 and 2021.

	First Bloom		Peak Bloom	
Cultivar	Mean	SD	Mean	SD
sunn hemp VNS	46	10	55	8.8
'Tropic Sun'	60	3.7	67	3.2

DAP days after planting
SD standard deviation

Table 13. Sunn hemp insect and disease at peak bloom, 2020 and 2021.

	Insect		Disease	
Cultivar	Mean	SD	Mean	SD
sunn hemp VNS	2.0	0.53	1.1	0.35
‘Tropic Sun’	2.0	0.00	1.0	0.0

SD standard deviation
Insect and disease ratings were based on a 0-3 scale: 0 = no damage, 3 = severe damage

Table 14. Sunn hemp biomass yield (dry lb/acre), 2020 and 2021.

Cultivar	Mean
sunn hemp VNS	5514 a*
‘Tropic Sun’	9406 b

* Means followed by different letters are significantly different at $P<0.05$

Clover

Clovers exhibited characteristics to be good cover crops for certain objectives. Both ‘Hubam’ white sweet clover and yellow blossom sweet clover VNS had excellent emergence (Table 15). However, the clovers had 24 to 35% cover at 28 DAP which is slow for a cover crop to produce a canopy cover that effectively suppresses weeds (Table 16). At the final measurement, canopy cover was nearly complete at 94 and 96% for Hubam white sweet clover and yellow blossom sweet clover VNS, respectively (Table 16). Both clovers had long growth periods before peak bloom, 65 to more than 91 DAP (Table 17). At 28 DAP, both clovers were very short, 12 cm or less, but Hubam white sweet clover increased in height to 147 cm while the final height of yellow blossom sweet clover VNS was only 41 cm (Table 18). Both clover varieties had little insect and disease damage (Table 19). Both clovers produced biomass yield less than the 8000 lb/acre needed for weed suppression (Treadwell et al., 2012a). Hubam white sweet clover and yellow blossom sweet clover VNS produced 6300 and 4382 lb/acre dry biomass, respectively (Table 20). These clovers emerged well to produce a full stand, bloomed late in the season, and resisted insect and disease damage. However, they were slow to produce canopy cover and did not produce adequate biomass to suppress weeds well.

Table 15. Clover emergence rating at 14 DAP, 2020 and 2021.

Cultivar	Mean	SD
Hubam white sweet clover	2.9	0.35
yellow blossom sweet clover VNS	2.9	0.35

DAP days after planting
SD standard deviation
Emergence scale: 0 = <25% (poor), 1 = 25 – 50 % (fair), 2 = 50-75% (good), 3 = >75% (excellent)

Table 16. Clover canopy cover %, 2020 and 2021.

	28 DAP		Peak Bloom	
Cultivar	Mean	SD	Mean	SD
Hubam white sweet clover	24	12	94	4.8
yellow blossom sweet clover VNS	35	19	96	5.5

DAP days after planting
SD standard deviation
Peak Bloom canopy cover measured at peak bloom or 91 DAP whichever was earlier

Table 17. Clover bloom DAP, 2020 and 2021.

Cultivar	First Bloom Mean	SD	Peak Bloom Mean	SD
Hubam white sweet clover	58	4.0	65	6.1
yellow blossom sweet clover VNS	> 91	†	> 91	†

DAP days after planting
SD standard deviation
† not estimable

Table 18. Clover plant height (cm) at 28 DAP and at peak bloom, 2020 and 2021.

Cultivar	28 DAP Mean	SD	Peak Bloom Mean	SD
Hubam white sweet clover	12	2.8	147	29.9
yellow blossom sweet clover VNS	8.8	2.7	41	4.9

DAP days after planting
SD standard deviation
Peak Bloom plant height measured at peak bloom or 91 DAP whichever was earlier

Table 19. Clover insect and disease at peak bloom, 2020 and 2021.

Cultivar	Insect Mean	SD	Disease Mean	SD
Hubam white sweet clover	1.0	0	1.0	0
yellow blossom sweet clover VNS	1.0	0	1.0	0

SD standard deviation
Insect and disease ratings were based on a 0-3 scale: 0 = no damage, 3 = severe damage
Insect and disease rating evaluated at peak bloom or 91 DAP whichever is earlier

Table 20. Clover biomass yield (dry lb/acre), 2020 and 2021.

Cultivar	Mean
Hubam white sweet clover	6300 a*
yellow blossom sweet clover VNS	4382 a

* Means followed by different letters are significantly different at $P<0.05$

Other Legumes

‘Rongai’ lablab has characteristics that would make it a good cover crop, but alfalfa VNS, mung bean VNS, and ‘Laredo’ soybean would be useful for specific objectives. All four of these legumes had fair to excellent emergence in the field (Table 21). Rongai lablab, mung bean VNS, and Laredo soybean produced quick canopy cover, but alfalfa VNS was slow (Table 22). Rongai lablab and alfalfa VNS had a longer vegetative phase while mung bean VNS and Laredo soybean were quick to reach peak bloom (Table 23). Alfalfa VNS had short stature at 28 DAP (17 cm) and at peak bloom (29 cm) while Rongai lablab, mung bean VNS, and soybean Laredo had heights ranging from 38 to 42 cm at 28 DAP and 65 to 96 cm at the final measurement (Table 24). All these legumes had somewhat light damage from insect and disease (Table 25). Only Rongai lablab produced sufficient dry biomass, 9595 lb/acre, to potentially suppress weeds effectively (Table 26). Rongai lablab had characteristics to make it an effective cover crop. Alfalfa VNS had some good characteristics for a cover crop but produced canopy cover slowly and low biomass. Mung bean VNS and Laredo soybean bloomed quickly and produced low biomass limiting their usefulness as cover crops.

Table 21. Other legumes emergence rating at 14 DAP, 2020 and 2021.

Cultivar	Mean	SD
alfalfa VNS	3.0	0.0
Rongai lablab	2.0	0.76
mung bean VNS	2.9	0.35
Laredo soybean	1.9	0.64

DAP days after planting
SD standard deviation
Emergence ratings scale: 0 = <25% (poor), 1 = 25 – 50 % (fair), 2 = 50-75% (good), 3 = >75% (excellent)

Table 22. Other legumes canopy cover %, 2020 and 2021.

	28 DAP		Peak Bloom	
Cultivar	Mean	SD	Mean	SD
alfalfa VNS	40	20	97	5.4
Rongai lablab	74	6.2	99	1.1
mung bean VNS	85	23	88	17
Laredo soybean	73	25	87	22

DAP days after planting
SD standard deviation

Table 23. Other legumes bloom DAP, 2020 and 2021.

	First Bloom		Peak Bloom	
Cultivar	Mean	SD	Mean	SD
alfalfa VNS	51	5.1	61	7.4
Rongai lablab	>91	na	>91	na
mung bean VNS	34	2.6	40	0.46
Laredo soybean	28	0.35	38	2.0

DAP days after planting
SD standard deviation

Table 24. Other legumes height (cm), 2020 and 2021.

	28 DAP		Peak Bloom	
Cultivar	Mean	SD	Mean	SD
alfalfa VNS	17	7.8	29	8.2
Rongai lablab	42	5.2	96	15
mung bean VNS	39	8.4	65	15
Laredo soybean	38	9.7	70	18

DAP days after planting
SD standard deviation

Table 25. Other legumes insect and disease at peak bloom, 2020 and 2021.

	Insect		Disease	
Cultivar	Mean	SD	Mean	SD
alfalfa VNS	2.1	1.4	2.1	1.4
Rongai lablab	1.4	0.52	1.0	0.0
mung bean VNS	1.5	0.53	1.0	0.0
Laredo soybean	1.8	0.46	1.0	0.0

SD standard deviation
Insect and disease ratings were based on a 0-3 scale: 0 = no damage, 3 = severe damage

Table 26. Other legumes biomass yield (dry lb/acre), 2020 and 2021.

Cultivar	Mean
alfalfa VNS	4345 a*
Rongai lablab	9595 b
mung bean VNS	3797 a
Laredo soybean	2812 a

*Means followed by different letters are significantly different at P<0.05

Grasses

The four large grasses evaluated possess traits that make them suitable cover crops. ‘Piper’ sudangrass, ‘Growers Choice’ sorghum, ‘Honey Graze’ sorghum-sudan, and ‘Leafy 22’ pearl millet emerged well and produced substantial canopy cover quickly (Tables 27 and 28). Piper sudangrass, Grower’s Choice sorghum, and Honey Graze sorghum-sudan had long vegetative phases (Table 29). Plant height ranged from 55 to 93 cm at 28 DAP and 157 to 269 cm at peak bloom the final measurement (Table 30). All four grasses were lightly damaged by insect and disease (Table 31), and biomass production was well above the 8000 dry lb./acre needed to potentially suppress weeds (Table 32; Treadwell et al., 2012a).

Table 27. Grasses emergence rating at 14 DAP, 2020 and 2021.

Cultivar	Mean	SD
Leafy 22 pearl millet	2.5	0.53
Grower’s Choice sorghum	2.1	0.83
Honey Graze sorghum-sudan	2.0	0.93
Piper sudangrass	2.9	0.35

DAP days after planting
SD standard deviation
Emergence ratings scale: 0 = <25% (poor), 1 = 25 – 50 % (fair), 2 = 50-75% (good), 3 = >75% (excellent)

Table 28. Grasses cover %, 2020 and 2021.

	28 DAP		Peak Bloom	
Cultivar	Mean	SD	Mean	SD
Leafy 22 pearl millet	83	21	95	5.3
Grower’s Choice sorghum	73	29	93	6.9
Honey Graze sorghum-sudan	60	37	83	16
Piper sudangrass	89	15	88	11

DAP days after planting
SD standard deviation

Table 29. Grasses bloom DAP, 2020 and 2021.

	First Bloom		Peak Bloom	
Cultivar	Mean	SD	Mean	SD
Leafy 22 pearl millet	45	3.1	51	0.53
Grower’s Choice sorghum	53	3.7	60	3.4
Honey Graze sorghum-sudan	66	6.7	71	8.4
Piper sudangrass	55	4.4	62	5.9

DAP days after planting
SD standard deviation

Table 30. Grasses plant heights (cm), 2020 and 2021.

	28 DAP		Peak Bloom	
Cultivar	Mean	SD	Mean	SD
Leafy 22 pearl millet	55	14	157	10.7
Grower's Choice sorghum	74	20	244	21.3
Honey Graze sorghum-sudan	66	24	231	34.3
Piper sudangrass	93	20	269	21.7

DAP days after planting
SD standard deviation

Table 31. Grasses insect and disease at peak bloom, 2020 and 2021.

	Insect		Disease	
Cultivar	Mean	SD	Mean	SD
Leafy 22 pearl millet	1.4	0.52	1.0	0.0
Grower's Choice sorghum	1.4	0.52	1.5	0.53
Honey Graze sorghum-sudan	1.4	0.52	1.9	1.1
Piper sudangrass	1.0	0.0	1.0	0.0

SD standard deviation
Insect and disease ratings were based on a 0-3 scale: 0 = no damage, 3 = severe damage

Table 32. Grasses biomass yield (dry lb/acre), 2020 and 2021.

Cultivar	Mean
Leafy 22 pearl millet	10949 a*
Grower's Choice sorghum	13171 a
Honey Graze sorghum-sudan	10820 a
Piper sudangrass	12990 a

*Means followed by different letters are significantly different at P<0.05

Cover crops can be used to mitigate compaction, control erosion, add nutrients and organic matter to the soil, and suppress weeds. For Hawaii and the Pacific Islands Area, weed suppression is the most common reason farmers use cover crops. Weed suppression can result from cover crop species quickly producing canopy cover that shade weeds and/or the cover crop produces high biomass yield that covers the soil surface after termination (Treadwell et al., 2012a; Treadwell et al., 2007). Biomass residue of 8000 to 12000 dry lb./acre is sufficient to suppress weed germination (Treadwell, 2012a). Plotting biomass yield versus canopy cover at 28 DAP shows 3 distinct groups of cover crop species (Figure 2). Species in the upper-right corner of the plot produced canopy cover of 60% or more at 28 DAP and biomass yield greater than 8000 dry lb/acre. The legume species in this group are Rongai lablab and Tropic Sun sunn hemp, and the grasses are Growers Choice sorghum, Piper sudangrass, and Honey Graze sorghum-sudan. The cover crop species in the lower-right of the plot are species that produce quick canopy cover, but less biomass yield, that would provide weed suppression during the period that the cover crop is growing. The cover species in this group are the legumes Chinese Red cowpea, Iron and Clay cowpea, Red Ripper cowpea, mung bean VNS, Laredo soybean, and sunn hemp VNS.

High biomass production can fulfill other objectives beside weed suppression such as improved soil aggregate stability, water holding capacity, and water infiltration rate (Sullivan, 2003; Treadwell et al., 2012a). The cover crop species in the upper-right corner of the plot in Figure 2 can be used for these purposes as well.

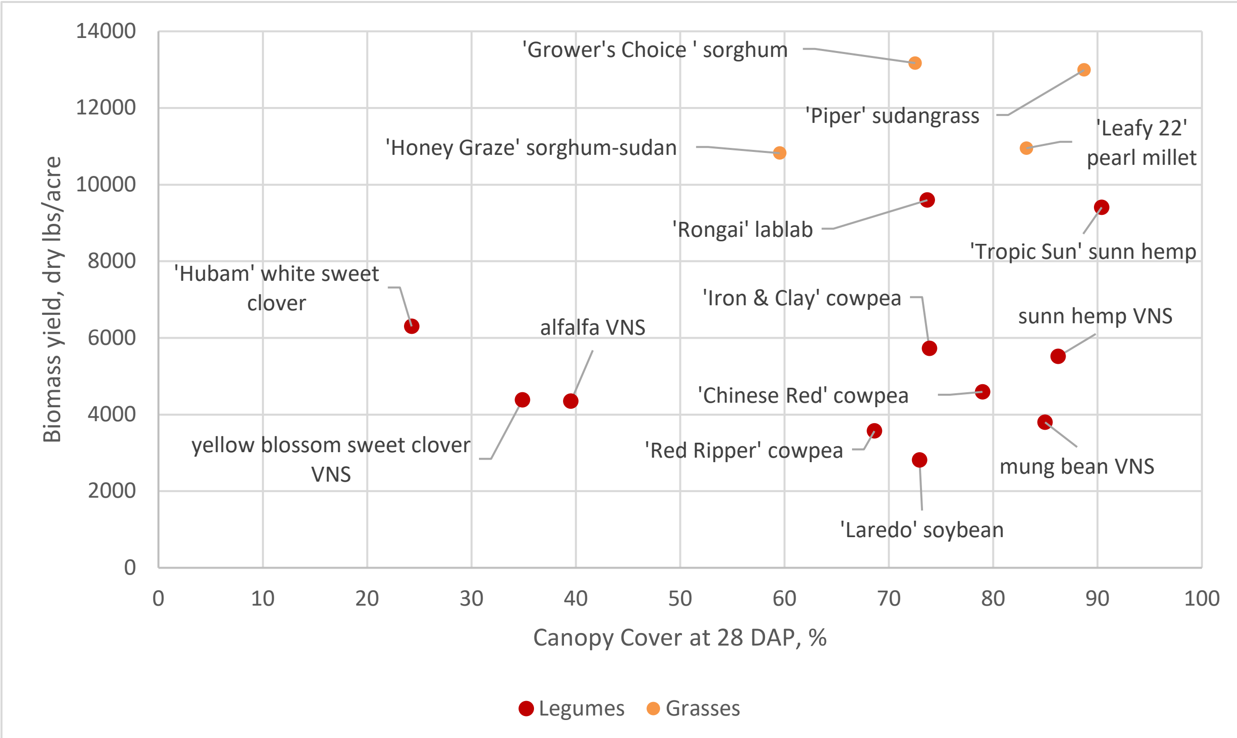

Figure 2. Plot canopy cover at 28 days after planting (DAP) and biomass yield for 15 varieties of 13 cover crop species grown at the Hoolehua Plant Materials Center, Hoolehua, Hawaii. Data are means over 2020 and 2021 plantings.

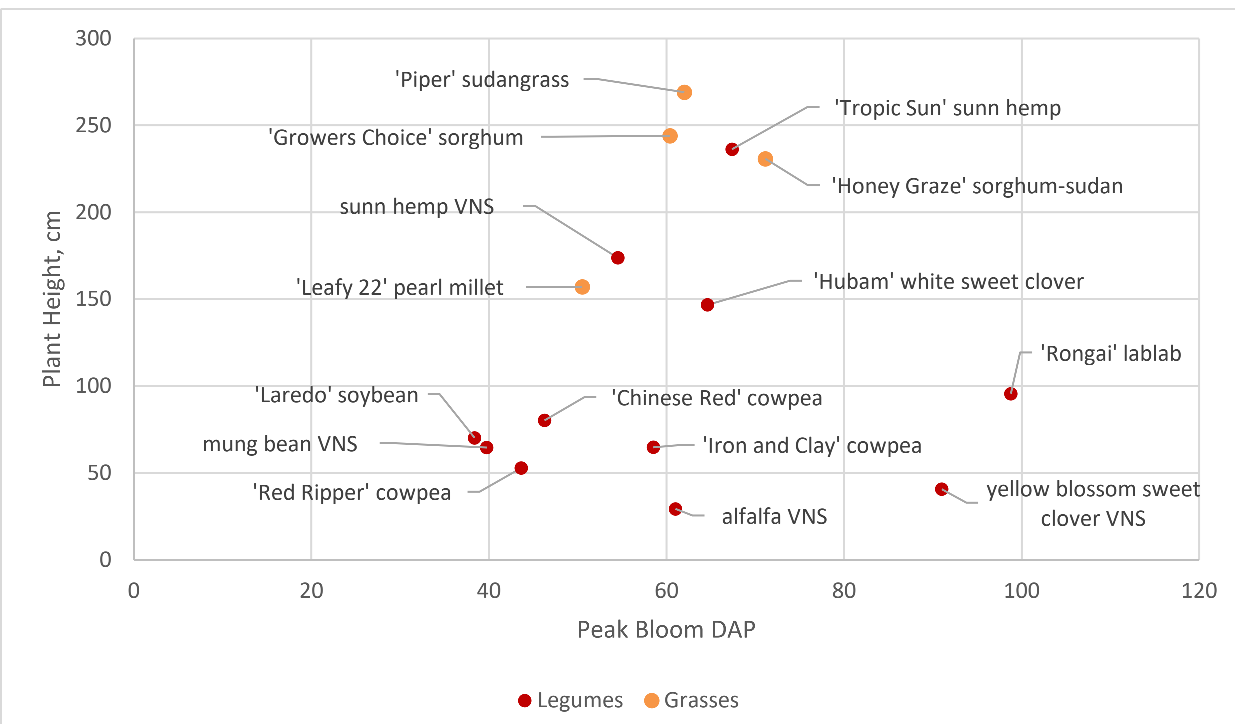

Figure 3. Plot of peak bloom days after planting (DAP) and biomass yield for 15 varieties of 13 cover crop species grown at the Hoolehua Plant Materials Center, Hoolehua, Hawaii. Data are means over 2020 and 2021 plantings.

Cover crop species are selected to fulfill grower objectives, but also need to fit in the cropping schedule (Treadwell et al., 2012b). The time-period from planting the cover crop to termination must fit between the harvest of the main crop and planting of the following main crop (Treadwell, et al., 2012b). The plot of peak bloom versus biomass yield shows the cover crop species that produce adequate biomass for weed suppression, i.e., greater than 8000 dry lb/acre, and the range of growth duration to peak bloom (Figure 3). Among the high biomass producing cover crops, Leafy 22 pearl millet had a growth duration to peak bloom of 50 days while Rongai lablab extended the growth duration to more than 91 days. Grower's Choice sorghum, Honey Graze sorghum-sudan, Piper sudangrass, and Tropic Sun sunn hemp had intermediate growth durations. The range of growth duration gives a producer options to select a variety that fits their cropping schedule.

Cover crop mixes can be implemented to enhance diversity and fulfill multiple objectives such as nitrogen addition, increased soil organic matter and weed suppression. Mixing legume and grass species could provide nitrogen for the main crop and weed suppression (Chapagain et al., 2020; Di Bella et al., 2021). Growing multiple plant species requires careful selection to ensure compatibility. Salon (2010) recommends cover crop species have similar heights and bloom near-simultaneously. Plants with similar heights produce a uniform canopy. Simultaneous blooming ensures full vegetative growth of all species instead of forcing termination whenever the earliest species blooms. The plot of peak bloom DAP versus plant height identifies cover crop species that are compatible in height and bloom date (Figure 4). If a mix of a legume and grass are desired, the legume Tropic Sun sunn hemp potentially could be matched with grasses Honey Graze sorghum sudan, Growers Choice sorghum, or Piper sudangrass (Figure 4). Similarly, the grass Leafy 22 pearl millet could be matched with legumes sunn hemp VNS or Hubam white sweet clover (Figure 4). Other compatibility factors should be considered such as root structure, however compatible plant height and bloom date are important when mixing species for cover cropping.

The cover crop species adaptation data in Tables 2 to 25 were produced as a basis for cover crop species selection to address producer objectives. Cover crop species were identified that are expected to provide weed suppression and flexibility in fitting the growth period into the window between main crops. However, there are limitations to application of this data. Insect and disease damage were assessed, but the causal insect and disease were not precisely identified. It is possible that the cover crop species may host the same causal agents as the main crop which would exclude the cover crop species as suitable. This study was conducted at one low-elevation site where irrigation and fertilizer were applied. The cover crop species performance would likely be different at high-elevation, different season, low-fertility soils or low-rainfall sites. Despite the limitations, this data helps fill the dearth of information to assess cover crop species in Hawaii and the Pacific Islands.

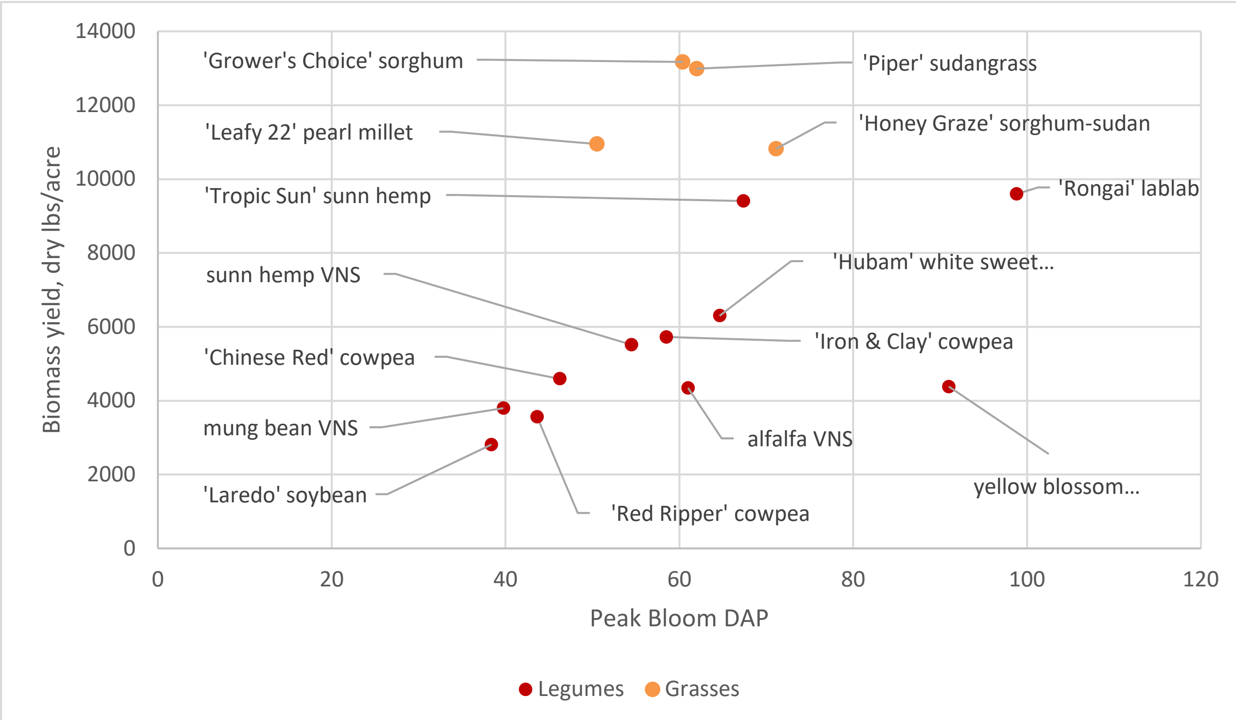

Figure 4. Plot of peak bloom days after planting (DAP) and plant height for 15 varieties of 13 cover crop species grown at the Hoolehua Plant Materials Center, Hoolehua, Hawaii. Data are means over 2020 and 2021 plantings.

CONCLUSION

The basic adaptation data developed in this study are useful for selecting cover crop species to meet conservation and soil properties objectives. Cover crop species Growers Choice sorghum, Honey Graze sorghum-sudan, Piper sudangrass, Rongai lablab, and Tropic Sun sunn hemp are expected to provide weed suppression during the cover crop growing season and as a residue cover after termination for a subsequent main crop. Cover crop species Growers Choice sorghum, Honey Graze sorghum-sudan, Piper sudangrass, Rongai lablab, and Tropic Sun sunn hemp provide a range of growth durations that gives growers options to schedule the cover crop between main crops. Mixing cover crop species, the legume Tropic Sun sunn hemp is compatible with grasses Honey Graze sorghum-sudan, Growers Choice sorghum or Piper sudangrass with similar heights and bloom dates. The grass Leafy 22 pearl millet is compatible with legumes sunn hemp VNS or Hubam white sweet clover in terms of height and bloom date. Large Lad soybean and Georgia Two pigeonpea are not recommended as a cover crop due to excessive predation by birds.

LITERATURE CITED

Chapagain, T., E.A. Lee, and M.N. Raizada. 2020. The potential of multi-species mixtures to diversify cover crop benefits. Sustainability 12, 2058. Doi: 10.3390/su12052058.

Di Bella, L., M. Zahmel, L. van Zwieten. And T.J. Rose. 2021. Weed suppression, biomass and nitrogen accumulation in mixed-species and single-species cover crops in a tropical sugarcane fallow. Agriculture 11, 640. Doi: 10.3390/agriculture11070640.

Duncan, J. 2017. Cover crop options for hot and humid areas. IP535, Appropriate Technology Transfer for Rural Areas, National Center for Appropriate Technology, Butte, MT.

Evans, D.O., R.J. Joy, and C.L. Chia. 1988. Cover crops for orchards in Hawaii. Research and

Extension Series 094, College of Tropical Agriculture and Human Resources, University of Hawaii, Honolulu, HI.

Evensen, C.I., and R.V. Osgood. 1991. Oat cover cropping in sugarcane for weed and erosion control in Hawaii. pp 30-31. Cover crops for clean water: The proceedings of an international conference, West Tennessee Experiment Station, April 9-11, 1991, Jackson, Tennessee.

Gomez, K.A., and A.A. Gomez. 1984. Statistical procedures for agricultural research. John Wiley and Sons, New York.

Manandhar, R., K.-H. Wang, C.R.R. Hooks, and M.G. Wright. 2017. Effects of strip-tilled cover cropping on the population density of thrips and predatory insects in a cucurbit agroecosystem. Journal of Asia-Pacific Entomology 20:1254-1259. Doil: 10.1016/j.aspen.2017.09.006

NIST. 2012. NIST/SEMATECH e-Handbook of Statistical Methods. http://www.itl.nist.gov/div898/handbook. Accessed July 22, 2022.

Radovich, T. 2010. Cover your asset: Choosing appropriate cover crops for your production system. Hanai Ai/The Food Provider, June-July-August 2010.

Salon, P.R. 2010. Diverse cover crop mixes for good soil health. Big Flats Plant Materials Center, Natural Resources Conservation Service, U.S. Department of Agriculture, Corning, NY.

Sipes, B.S., and A.S. Arakakai. 1997. Root-knot nematode management in dryland taro with tropical cover crops. Supplement to the Journal of Nematology 29(4S):721-724.

Sullivan, P. 2003. Overview of cover crops and green manures. Appropriate Technology Transfer for Rural Areas, National Center for Appropriate Technology, Butte, MT.

Treadwell, D.D., N.G. Creamer, J.R. Schultheis, and G.D. Hoyt. 2007. Cover crop management influences weed suppression in organically managed sweetpotato systems. Weed Technology 21:1039-1048. Doi: 10.1614/WT-07-005.1

Treadwell, D., K. Waldemar, and M. Alligood. 2012a. Annual cover crops in Florida vegetable systems Part 1. Objectives: Why grow cover crops? HS387, Horticultural Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

Treadwell, D., W. Klassen, and M. Alligood. 2012b. Annual cover crops in Florida vegetable systems Part 2: Production. HS1141, Horticultural Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

Wang, K.-H., B.S. Sipes, and D.P. Schmitt. 2002. *Crotalaria* as a cover crop for nematode management: A review. Nematropica 32:35-57.

Waisen, P., Z. Cheng, B.S. Sipes, and K.-H. Wang. 2022. Biofumigation effects of brassicaceous cover crops on soil health in cucurbit agroecosystems in Hawaii, USA. Pedosphere 32:521-531. Doi: 10.1016/S1002-0160(21)60054-1.

Wallander, S., D. Smith, M. Bowman, and R. Claassen. 2021. Cover crop trends, programs, and practices in the United States. Economic Information Bulletin No. 222, Economic Research Service. U.S. Department of Agriculture.

discriminating based on race, color, national origin, religion, sex, gender identity (including gender expression), sexual orientation, disability, age, marital status, family/parental status, income derived from a public assistance program, political beliefs, or reprisal or retaliation for prior civil rights activity, in any program or activity conducted or funded by USDA (not all bases apply to all programs). Remedies and complaint filing deadlines vary by program or incident.

Persons with disabilities who require alternative means of communication for program information (e.g., Braille, large print, audiotape, American Sign Language, etc.) should contact the responsible Agency or USDA's TARGET Center at (202) 720-2600 (voice and TTY) or contact USDA through the Federal Relay Service at (800) 877-8339. Additionally, program information may be made available in languages other than English.

To file a program discrimination complaint, complete the USDA Program Discrimination Complaint Form, AD-3027, found online at How to File a Program Discrimination Complaint and at any USDA office or write a letter addressed to USDA and provide in the letter all of the information requested in the form. To request a copy of the complaint form, call (866) 632-9992. Submit your completed form or letter to USDA by: (1) mail: U.S. Department of Agriculture, Office of the Assistant Secretary for Civil Rights, 1400 Independence Avenue, SW, Washington, D.C. 20250-9410; (2) fax: (202) 690-7442; or (3) email: program.intake@usda.gov.

USDA is an equal opportunity provider, employer, and lender.

Helping People Help the Land