Survey of Irrigation Methods in California in 2010

Gwen N. Tindula[1]; Morteza N. Orang[2]; and Richard L. Snyder[3]

Abstract: Reliable information on irrigation methods is important for determining agricultural water demand trends. The authors have therefore conducted a study over the course of 2011 to collect information on the irrigation methods that were used by growers to irrigate their crops in 2010. The results were compared with earlier surveys to assess trends in cropping and irrigation methods. A one-page questionnaire was developed to collect information on irrigated land by crop and irrigation method. The questionnaire was mailed to 10,000 growers in California who were randomly selected from a list of 58,000 growers by the USDA National Agricultural Statistics Service, excluding rice, dry land, and livestock producers. From 1972–2010, the planted area has increased from 15 to 30% for orchards and from 6 to 15% for vineyards. The area planted with vegetables has remained relatively static, whereas that planted to field crops has declined from 67 to 41% of the irrigated area. The land irrigated with low-volume (drip and micro-sprinkler) irrigation has increased by approximately 38%, whereas the amount of land irrigated by surface methods has decreased by approximately 37%. **DOI: 10.1061/(ASCE)IR.1943-4774.0000538.** *© 2013 American Society of Civil Engineers.*

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Introduction

Surface (i.e., gravity-driven), sprinkler, and low-volume (i.e., drip and micro-sprinkler) irrigation are the primary methods that are used by growers to irrigate crops within California. There is also a small amount of irrigated area with subsurface irrigation, in which drain tiles or open channels are blocked to force water into the root zone of crops. However, this area is insignificant relative to the other methods. The most appropriate irrigation method for a region depends upon the physical site conditions, crops being grown, amount of water available, and management skill.

In all irrigation methods, the goal is to attain high distribution uniformity with minimal runoff and deep percolation. Generally, more water is applied with surface and sprinkler irrigation on an annual basis than with drip and micro-sprinkler (drip/micro) systems because it is easier to achieve high distribution uniformity with the low-volume methods. For surface irrigation, it is often difficult to control the application depth of irrigation water because of uniformity and timing constraints. Typically, low-volume systems have lower wetted surface areas than other methods, which can lead to less soil evaporation depending on the irrigation frequency of the other methods. Drip/micro irrigation is generally more flexible for scheduling because timing and the amount applied are more controlled by the irrigator than the water delivery system.

To update California's records on crops and irrigation methods, the California Department of Water Resources (CDWR) has conducted a survey roughly every 10 years during recent decades. The survey data were analyzed and compared with earlier studies to determine how irrigation methods have changed and to make projections of future changes. This paper reports on the results from the 2010 irrigation survey and identifies trends in irrigation method usage.

Methodology

Questionnaire Design and Distribution

In 2011, a one-page grower questionnaire (Fig. 1) was mailed to 10,000 growers in California to determine what irrigation methods were used on which crops during 2010. The 2010 questionnaire and its distribution were similar to the surveys completed in 1991 (Snyder et al. 1996) and 2001 (Orang et al. 2008). Irrigation system surveys also were conducted in 1972 (Stewart 1975) and 1980 (Hagan and Wagner 1983), but the University of California cooperative extension specialists and farm advisors in each county estimated the irrigated crop area. In 2011, the mailing list was randomly selected from a list of 58,000 growers, excluding rice, dry land, and livestock only, by the California office of the USDA National Agricultural Statistics Service. The number of questionnaires mailed to each county was proportional to the ratio of growers residing in each county to the statewide total. There was an excellent 51% useable return rate.

Crops

In the questionnaire, growers were asked to state the primary county in which they farmed and the area they planted to each of 20 possible crops by irrigation method within that county during 2010. The 2010 and 2001 surveys included 20 crop categories as

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ACREAGE IRRIGATED BY CROP AND BY IRRIGATION METHODS IN 2010

What is the name of the main county where you farm? _____. Please fill in the **number of acres** of each crop irrigated by each method in **2010** (include only those acres in the main county where you farm).

In the shaded cell, below the number of acres, enter the **main water source** for that irrigation system and crop: **S = surface water, G=ground water, or B = both**

CROP (not including rice)		IRRIGATION METHOD																
		SUBSURFACE	SURFACE				SURFACE/SPRINKLER		SPRINKLER								DRIP	
		DRAIN PIPE OR DITCH (NOT DRIP)	WILD FLOOD	BORDER	BASIN	FURROW	FURROW SIDE-ROLL	FURROW HAND-MOVE	PERMANENT	HAND-MOVE	LINEAR-MOVE	SIDE-ROLL	MICRO-MINI	HOSE-PULL	CENTER - PIVOT	ABOVE GROUND	BURIED DRIP
CORN	Acres																
	Source																
COTTON	Acres																
	Source																
DRY BEANS	Acres																
	Source																
GRAINS (1)	Acres																
	Source																
SAFFLOWER	Acres																
	Source																
SUGAR BEETS	Acres																
	Source																
OTHER FIELD CROPS (2)	Acres																
	Source																
ALFALFA	Acres																
	Source																
PASTURE (3)	Acres																
	Source																
CUCURBITS (4)	Acres																
	Source																
ONION & GARLIC	Acres																
	Source																
POTATO	Acres																
	Source																
TOMATO (FRESH)	Acres																
	Source																
TOMATOES (PROCESSING)	Acres																
	Source																
OTHER TRUCK CROPS (5)	Acres																
	Source																
ALMOND & PISTACHIO	Acres																
	Source																
OTHER DECIDUOUS (6)	Acres																
	Source																
SUBTROPICAL TREES (7)	Acres																
	Source																
TURFGRASS & LANDSCAPE	Acres																
	Source																
VINEYARD	Acres																
	Source																

[1]wheat, oats, barley, etc; [2]sorghum, sunflower, sudangrass, etc; [3]excluding grass hay; [4]melons, squash, cucumbers, etc; [5]carrots, celery, cauliflower, broccoli, strawberries, asparagus, etc; [6]apples, peaches, prunes, pears, etc; [7]olives, avocados, citrus, dates, etc.

Fig. 1. Sample of the irrigation survey form to gather irrigated acreages by crop and by irrigation method in 2010

opposed to 13 crop categories used in the 1991 survey. A list of crops used in the 1972, 1980, 1991, 2001, and 2010 surveys are shown in Table 1.

Irrigation Methods

Irrigation method choices include surface (gravity), sprinkler, low-volume (micro-sprinkler/drip), and sub-surface methods. A more detailed description for each irrigation method can be found in Merriam and Keller (1978). General descriptions are given next.

- Subsurface irrigation. Underground pipes or open ditches are blocked to back up ground water and force it up into a crop root zone. This method is primarily used in the Sacramento-San Joaquin River Delta.
- Surface irrigation. This includes wild flood, border, basin, furrow irrigation without sprinklers, wheel-line sprinklers followed by furrow irrigation, and hand move sprinklers followed by furrow irrigation. Land that is irrigated initially with sprinklers and subsequently with furrows is included in this category.

Table 1. Crop Types Used in the 1972, 1980, 1991, 2001, and 2010 Surveys

2001 and 2010 crops	1991 crops	1980 crops	1972 crops
Alfalfa	Alfalfa	Alfalfa	Alfalfa
Grain	Small grains	Grain	Small grains, misc. hay
Corn	Corn	Corn	Corn
Cotton	Cotton	Cotton	Cotton
Other field crops, beans, safflower	Other field crops	Misc. field	Other field crops
Pasture, turfgrass, and landscape	Pasture	Pasture	Pasture
Almonds and pistachios, other deciduous	Deciduous fruits and nut trees	Deciduous fruits and nut trees	Peaches and nectarines, prunes, almonds, walnuts
Subtropical orchard	Subtropical orchard	Subtropical orchard	Citrus and avocado, other orchard
Sugar beets	Sugar beets	Sugar beets	Sugar beets
Tomato (fresh), tomato (process)	Tomato (process)	Tomatoes	Tomatoes
Other truck crops, onion and garlic, potato, cucurbit	Vegetables (truck crops)	Misc. truck crops	Beans (all types), potatoes, lettuce, other vegetable crops
Vineyard	Grapes and bush berries	Vineyard	Grapes
		Rice	Rice

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- Sprinkler irrigation. Sprinkler methods include solid set, hand-move, linear-move, wheel-line, hose-pull, and other types, including center pivot, gun-type, and so on.
- Low-volume (drip and micro-sprinkler) irrigation. This includes all low-volume systems, including surface and buried drip irrigation, micro-irrigation, and mini-sprinklers.

Micro-sprinklers were included with surface and buried drip in the low-volume method category in the 2001 and 2010 surveys, although they were listed in the sprinkler category in the 1991 study. To be consistent, micro-sprinkler areas from the 1991 survey were combined with surface and buried drip methods to compare with the 2001 and 2010 results.

Results and Discussion

Irrigation Methods in 2010

Table 2 presents the 2010 irrigated area by crop and irrigation method, and the percentage of irrigated land by crop categories for each of the four irrigation methods is shown in Table 3. In general, field crops were surface irrigated, whereas tree and vine crops were irrigated primarily with low-volume systems.

Comparisons with 2001

The irrigated land area for each crop and irrigation methods during 2010, 2001, and 1991 are shown in Tables 2, 4, and 5, respectively. To simplify comparisons, the crops were combined into four crop groups (i.e., field crops, vegetable crops, orchards, and vineyards) and the percentages of the total area irrigated by each of the four irrigation method categories are shown for 1991, 2001, and 2010 (Table 6). From 2001–2010, surface irrigation has declined and low volume irrigation increased in all crops. Drip irrigation in the orchard crops remained relatively static. The largest increase in use of drip irrigation was in the vegetable crops, an increase of 20% since 2001. A decrease in sprinkler irrigation was observed in vegetable crops and vineyards, whereas sprinkler usage changed little in orchard and field crops.

Comparisons with 1991

In the period from 1991–2010, an increase in drip and micro-sprinkler irrigation and a decrease in surface irrigation were evident for all crop categories. The crop categories that had the most significant increases in drip/micro irrigation since 1991 were

Table 3. Percentage of Irrigated Land Area by Crop and Irrigation Category Reported for 2010

Crop	Gravity	Sprinkler	Drip/micro	Subsurface
Corn	78	1	7	14
Cotton	73	7	15	4
Dry beans	66	21	12	0
Grains	79	13	3	5
Safflower	54	44	0	1
Sugar beet	85	3	12	0
Other field crops	69	15	14	2
Alfalfa	77	18	2	3
Pasture	69	26	5	1
Cucurbit	50	11	39	0
Onion-garlic	19	39	42	0
Potato	2	81	17	0
Tomato (fresh)	44	11	45	0
Tomato (process)	33	4	63	0
Other truck crops	24	40	35	0
Almond-pistachio	13	14	71	1
Other deciduous	31	27	40	1
Subtropical trees	6	15	76	4
Turfgrass-landscape	1	79	20	0
Vineyard	20	2	75	2
Total area	43	15	39	3

Note: All values are rounded to the nearest percentage.

Table 2. Irrigated Land (Hectares) by Crop and Irrigation Method Observed in 2010

	Irrigation method															
	SS	Surface						Sprinkler						Low-volume		
Crop	SS	WF	BR	BN	FW	SSR	SHM	PT	HM	LM	SR	CP	HP	MM	SD	BD
Corn	5,596	7,930	5,679	202	17,562	0	1,009	4	48	65	97	164	36	0	937	1,982
Cotton	641	1,530	767	0	8,448	0	231	0	660	445	0	0	0	0	1,049	1,271
Dry beans	4	64	578	0	1,714	0	457	246	344	0	99	202	0	0	131	392
Grains	2,104	10,059	11,897	2,419	11,022	49	29	3	2,023	722	1,405	1,700	16	0	159	1,313
Safflower	8	73	0	0	279	0	0	0	288	0	0	0	0	0	0	0
Sugar beet	0	0	0	0	842	0	0	2	28	0	0	0	0	0	0	113
Other field crops	260	2,892	4,215	696	3,174	0	115	4	1,673	16	136	520	53	2	780	1,463
Alfalfa	1,708	12,955	26,119	900	9,992	133	227	44	1,901	1,411	2,349	5,917	8	0	437	1,183
Pasture	237	5,375	5,180	395	608	44	65	957	2,130	103	862	219	82	0	0	767
Cucurbit	0	0	0	0	1,321	0	0	46	205	0	25	0	0	0	403	617
Onion-garlic	10	0	0	0	500	0	188	889	469	0	32	20	0	0	504	994
Potato	0	8	0	0	23	0	2	1,246	77	0	0	20	0	0	262	17
Tomato (fresh)	1	16	0	0	900	0	0	8	223	0	0	0	0	4	459	488
Tomato (process)	57	0	486	0	4,568	0	891	202	282	0	190	0	0	0	1,846	9,462
Other truck crops	57	111	538	0	6,671	0	1,781	4,648	10,406	0	0	128	0	94	9,411	3,669
Almond-pistachio	1,012	3,103	4,243	364	1,978	13	32	9,077	658	6	123	255	102	24,319	24,164	3,450
Other deciduous	561	1,283	4,272	605	7,303	51	22	9,374	1,674	109	2	24	515	11,086	5,016	1,236
Subtropical trees	1,308	221	828	112	753	62	34	4,742	126	7	51	53	343	16,248	10,241	730
Turfgrass-landscape	0	0	13	0	4	0	0	150	973	73	225	40	1	86	280	12
Vineyard	1,481	1,337	1,184	92	12,105	8	4	1,627	4	0	0	38	0	611	52,014	2,120

Note: SS = subsurface; WF = wild flood; BR = border; BN = basin; FW = furrow; SSR = furrow and side-roll sprinkler; SHM = furrow and hand-move sprinkler; PT = permanent sprinkler; HM = hand-move sprinkler; LM = linear-move sprinkler; SR = side-roll sprinkler; HP = hose pull sprinkler; CP = center-pivot sprinkler; MM = micro-sprinkler; SD = surface drip; and BD = buried drip.

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Table 4. Irrigated Land (Hectares) by Crop and Irrigation Method Reported for 2001

	Irrigation method															
	SS	Surface						Sprinkler						Low-volume		
Crop	SS	WF	BR	BN	FW	SSR	SHM	PT	HM	LM	SR	CP	HP	MM	SD	BD
Corn	1,693	746	1,891	26	9,345	0	138	20	1	0	0	89	0	0	1	0
Cotton	154	0	283	0	13,135	809	40	264	512	0	0	0	0	0	0	0
Dry beans	0	8	28	49	453	0	156	0	362	0	0	162	0	0	0	0
Grains	236	779	7,084	28	1,360	29	60	32	568	20	289	204	12	0	2	0
Safflower	127	105	100	34	263	0	0	0	243	0	0	0	0	0	0	0
Sugar beet	0	0	0	0	691	0	0	0	0	0	0	0	0	0	0	1
Other field crops	10	81	1,386	0	1,183	0	0	6	225	2	118	51	0	3	49	0
Alfalfa	625	518	19,456	91	2,149	0	190	19	979	949	1,749	1,151	16	0	0	0
Pasture	609	4,500	4,150	98	344	453	130	348	1,027	819	235	91	82	0	0	0
Cucurbit	0	7	6	0	111	0	56	2	81	0	10	0	0	0	20	104
Onion-garlic	0	0	0	0	123	0	237	334	129	0	0	0	0	0	1	0
Potato	0	0	0	0	15	0	0	17	1,105	0	0	0	0	0	93	0
Tomato (fresh)	0	0	0	0	739	124	817	1	0	0	0	0	0	0	163	897
Tomato (process)	0	0	0	0	1,541	200	349	0	930	0	0	0	0	0	30	30
Other truck crops	0	0	0	12	2,270	0	2,828	111	5,214	4	0	5	42	99	2,630	931
Almond-pistachio	64	660	4,034	506	206	63	732	3,201	332	0	4	0	111	13,968	7,647	761
Other deciduous	64	530	1,836	238	2,445	23	15	3,227	1,007	32	32	40	313	2,228	2,825	229
Subtropical trees	145	68	87	446	926	45	41	1,468	149	2	188	23	171	10,274	1,772	244
Turfgrass-landscape	1	0	2	0	0	0	0	17	83	0	243	0	10	10	30	0
Vineyard	62	74	307	223	6,108	26	49	2,731	106	0	0	12	0	423	21,395	1,053

Note: The data is from Orang et al. (2008). SS = subsurface; WF = wild flood; BR = border; BN = basin; FW = furrow; SSR = furrow and side-roll sprinkler; SHM = furrow and hand-move sprinkler; PT = permanent sprinkler; HM = hand-move sprinkler; LM = linear-move sprinkler; SR = side-roll sprinkler; HP = hose pull sprinkler; CP = center-pivot sprinkler; MM = micro-sprinkler; SD = surface drip; and BD = buried drip.

Table 5. Irrigated Land (Hectares) by Crop and Irrigation Method Reported for 1991

	Irrigation method																
	Surface						Sprinkler						Low-volume				SS
Crop	WF	BR	BN	FW	SSR	SHM	PT	HM	LM	SR	HP	OR	MM	SD	BD	DS	SS
ALF	1,868	20,151	229	1,765	0	0	18	1,280	0	1,204	209	809	121	10	0	0	263
SGR	512	9,171	183	3,528	68	781	0	751	40	824	0	121	0	0	0	0	67
CRN	228	1,856	14	4,578	18	550	0	0	0	0	0	0	0	0	0	0	65
CTN	0	5,407	0	16,370	162	4,769	190	1,557	0	0	0	101	0	0	65	0	0
OTH	735	3,652	787	3,635	143	292	279	167	0	441	0	54	17	9	68	0	49
PAS	3,756	3,789	67	1,063	0	64	204	809	18	71	69	111	0	0	0	0	660
DEC	1,735	8,445	397	5,225	169	436	11,552	3,249	49	3	966	179	3,775	3,516	1,522	490	104
SUB	105	101	226	1,310	0	95	1,400	118	16	98	836	69	10,286	1,193	58	9	0
SBT	0	72	0	3,492	316	575	47	634	0	0	0	0	0	0	0	0	0
TOM	0	136	0	5,390	668	6,853	30	604	0	279	0	0	0	0	121	0	0
VEG	125	218	61	5,316	866	4,152	3,295	1,458	987	0	0	0	1	1,100	1,692	202	0
VIN	526	1,223	316	7,045	190	193	2,513	112	0	0	36	0	15	8,745	121	62	57
Total	9,590	54,221	2,279	58,717	2,600	18,759	19,528	10,738	1,110	2,919	2,116	1,444	14,214	14,573	3,647	763	1,265

Note: The data is from Snyder et al. (1996). ALF = alfalfa; SGR = small grains; CRN = corn; OTH = other field crops; PAS = pasture; DEC = deciduous orchard; SUB = subtropical orchard; SBT = sugar beet; TOM = tomato; VEG = vegetables; and VIN = vineyards. WF = wild flood; BR = border; BN = basin; FW = furrow; SSR = furrow with side-roll sprinklers; SHM = furrow with hand-move sprinklers; PT = permanent sprinkler; HM = hand move sprinkler; LM = linear move sprinkler; SR = side-roll sprinkler; HP = hose pull; OR = other type of sprinkler; MM = micro-sprinkler; SD = surface drip; BD = buried drip; DS = drip following sprinkler; and SS = subsurface.

vegetables, orchards, and vineyards, with a 32, 28, and 33% increase in low-volume irrigation, respectively. The most prominent decrease in surface-irrigated land occurred in vegetable crops, with a decrease of 41% since 1991. From 1991–2010, sprinkler irrigated land increased in field and vegetable crops and decreased in orchards and vineyards.

Comparisons with Previous Years

Trends in irrigation method usage are shown in Fig. 2 and trends in cropping are shown in Fig. 3 for the period 1972–2010. The percentage of irrigated land by irrigation method shows decreasing use of surface irrigation and increasing use of drip and micro-sprinkler irrigation (Fig. 2). Clearly, much of the change in irrigation systems up to 2001 was driven by the decrease in field crop planting and an increase in orchards and vineyards where micro/drip irrigation is more widely practiced (Figs. 2 and 3). Although cropping changes were large from 1980–2001, from 2001–2010, there were only small changes in area planted for each of the crop groups in our sample (Fig. 3).

There was a small temporary decrease in sprinkler irrigation and a sustained increase in micro/drip irrigation in the 1991 survey. The

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Table 6. Percentages of Irrigated Land by Four Crop Categories and Four Irrigation Methods by Observation Year

Method	Year	Field	Vegetable	Orchard	Vineyard	All
Surface	1991	89	71	32	45	67
Sprinkler	1991	9	20	32	13	17
Micro/drip	1991	0	9	36	42	15
Subsurface	1991	1	0	0	0	1
Surface	2001	84	43	20	21	50
Sprinkler	2001	12	36	16	9	16
Micro/drip	2001	0	21	63	70	33
Subsurface	2001	4	0	0	0	2
Surface	2010	76	30	17	20	43
Sprinkler	2010	13	29	18	2	15
Micro/drip	2010	6	41	64	75	38
Subsurface	2010	5	0	2	2	3

Note: All values are rounded to the nearest percentage.

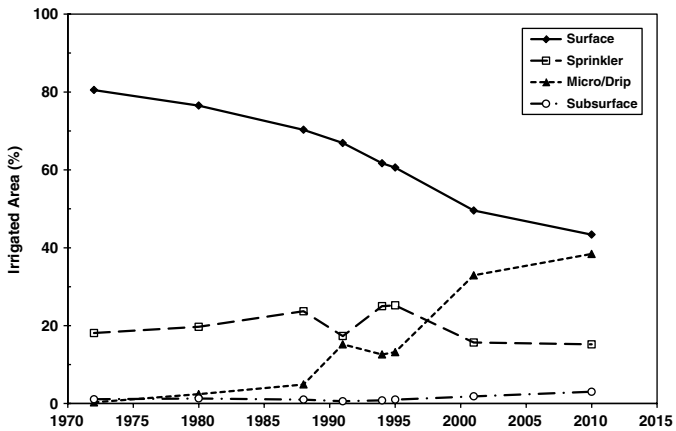

Fig. 2. Trends in irrigated area (percent) by irrigation system category

drought from 1988–1992 was the likely cause for the drop in sprinkler and increase in drip/micro usage. Following the drought, the area irrigated with micro/drip irrigation changed little until 1995 when it increased dramatically until 2001. Given that the capital costs to install micro/drip systems is somewhat high, perhaps several years of operation were needed to justify the investment before the increased adoption of the irrigation method.

Trends in the percentage of land irrigated by drip/micro systems, sprinklers, and surface irrigation for the four crop categories from the 1991, 2001, and 2010 surveys are shown in Table 6. From 1991–2001, little change occurred in the irrigation methods used on field crops, but there was a definite increased usage of drip/micro systems for vineyards and orchards. The large increase in drip/micro irrigation in vineyards and orchards from 1991–2001 was most likely because the low-volume systems were installed in new plantings rather than converting from other irrigation methods. For sprinklers, the primary changes were an increase of 16% in use on vegetable crops and a decrease of 16% in use for orchards during the period from 1991–2001. From 2001–2010, the trend for increasing drip/micro irrigation in vineyards and orchards slowed dramatically (Table 6) as new plantings of these crops declined (Fig. 3). Much of the change in usage of drip/micro irrigation resulted from converting surface irrigation of vegetable crops from 2001–2010 (Table 6). Since 2001, sprinkler use in vegetables has decreased by approximately 7% (Table 6).

The irrigation system trends seemed to be primarily related to the transition from field to orchard and vine crops regardless of the region within the state. Most of the drop in surface irrigation and

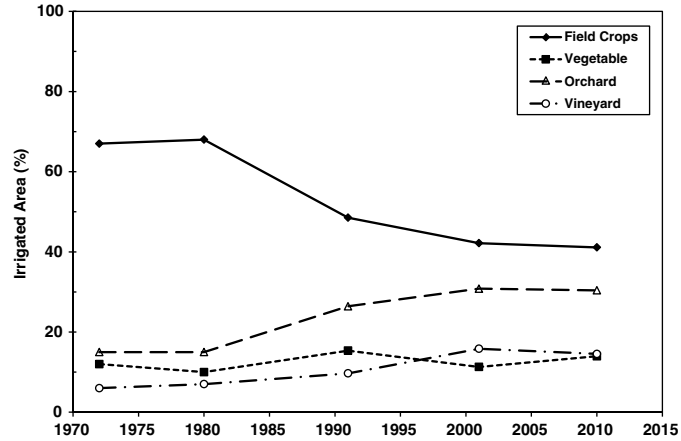

Fig. 3. Trends in irrigated area (percent) by crop category

increase in drip/micro system irrigated area from 1972–2010 was because of a decrease in field crops (approximately 27%) and approximately the same increase in vineyard, orchard, and vegetable crop area combined. Trends similar to the presented statewide averages were observed in the major agricultural regions (San Joaquin and Sacramento valleys) in which the primary transition from field to permanent crops has occurred.

Orchardists have adopted the use of micro-sprinklers to improve distribution uniformity, flexibility in scheduling, fertilizer application, protection against frost damage, and higher production. Except for frost protection, viticulturalists prefer elevated drip irrigation systems for similar reasons. In addition, the elevated drip lines do not interfere with cultural practices. The labor time for managing and maintaining drip/micro systems are comparable with other methods, but the type of labor is different and growers tend to prefer low-volume systems.

Conclusions

The results of the 2010 irrigation system survey are indicative of changing trends in crop areas and irrigation methods. A decrease in the use of surface irrigation by approximately 37% from 1972 until 2010 and an increase in use of drip/micro systems by approximately 38% were observed. The changes are primarily attributable to a drop in field crop planting from 1980–2010 (−27%), which are predominantly surface irrigated, and an increase in orchard and vineyard planting (+23%), which are primarily irrigated with drip/micro systems. From 2001–2010, reductions in new plantings of vineyards and orchards have slowed the trend for increasing usage of drip/micro systems for those crops, but vegetable growers show an increasing trend to change from surface irrigation to drip/micro systems. Over the course of the past decade, surface irrigation acreage decreased by approximately 7% and drip/micro irrigation usage increased by approximately 5% for all crops.

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