

# AV Profit

Bijesh Mishra, Ph.D.

2024-12-06

## Table of contents

<b>1</b>	<b>Setting Up</b>	<b>4</b>
1.1	Housekeeping . . . . .	4
1.2	Load libraries . . . . .	4
<b>2</b>	<b>Import data</b>	<b>5</b>
2.1	Tomato AV . . . . .	5
2.1.1	Calculate tavp_wocp . . . . .	6
2.1.2	TAV Profit > Tomato Alone . . . . .	9
2.1.3	Tax Credit for TAV . . . . .	10
2.2	Strawberry AV . . . . .	12
2.2.1	Calculate sbvp_wocp . . . . .	12
2.2.2	SBAV Profit > Strawberry Alone . . . . .	13
2.2.3	Tax Credit for SBAV . . . . .	14
<b>3</b>	<b>Tomato AV Results</b>	<b>15</b>
3.1	tav_profit Crosstab . . . . .	15
3.2	tav_profit Heatmap . . . . .	18
3.3	tav_profit manuscript . . . . .	20
3.4	tavp_wocp Crosstab . . . . .	23
3.5	tavp_wocp Heatmap . . . . .	25
3.6	tav_be_yld Crosstab . . . . .	26
3.7	tav_be_yld Heatmap . . . . .	29
3.8	Plot Tomato Profits by Panels . . . . .	30
3.9	Plot Tomato Profits by Yields . . . . .	32
<b>4</b>	<b>Strawberry AV Results</b>	<b>34</b>
4.1	sbav_profit Crosstab . . . . .	34
4.2	sbav_profit Heatmap . . . . .	36
4.3	sbav_profit manuscript . . . . .	38

4.4	sbavp_wocp Crosstab . . . . .	41
4.5	sbavp_wocp Heatmap . . . . .	43
4.6	sbav_be_yld Crosstab . . . . .	44
4.7	sbav_be_yld Heatmap . . . . .	47
4.8	Plot Strawberry Profit by Panels . . . . .	48
4.9	Plot Strawberry Profit by Yields . . . . .	50

NOTE: RUN “SUMULATION R50” BEFORE RUNNING THIS CODE FOR UPDATED  
INFORMATION.

Analysis in this file start by loading data saved after simulating tomato and strawberry AV profits. See simulation file for more details. The result tables I have here are quite big. Results are summarized in separate excel files.

# 1 Setting Up

## 1.1 Housekeeping

```
# #| echo: TRUE
rm(list = ls()) # Clean the environment.
options(
  warn=0, # Warnings. options(warn=-1) / options(warn=0)
  scipen=999 # No scientific notations.
)
```

## 1.2 Load libraries

```
library(tidyverse, warn.conflicts = FALSE, quietly = TRUE)
```

```
-- Attaching core tidyverse packages ----- tidyverse 2.0.0 --
v dplyr      1.1.4      v readr      2.1.5
v forcats    1.0.0      v stringr    1.5.1
v ggplot2    3.5.1      v tibble     3.2.1
v lubridate  1.9.3      v tidyr      1.3.1
v purrr      1.0.2
```

```
-- Conflicts ----- tidyverse_conflicts() --
```

```
x dplyr::filter() masks stats::filter()
```

```
x dplyr::lag()     masks stats::lag()
```

```
i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become
```

```
library(psych, warn.conflicts = FALSE, quietly = TRUE)
library(likert, warn.conflicts = FALSE, quietly = TRUE)
library(mice, warn.conflicts = FALSE, quietly = TRUE)
library(openxlsx2, warn.conflicts = FALSE, quietly = TRUE)
library(ggpubr, warn.conflicts = FALSE, quietly = TRUE)
library(gmodels, warn.conflicts = FALSE, quietly = TRUE)
library(reshape2, warn.conflicts = FALSE, quietly = TRUE)
```

```
library(arrow, warn.conflicts = FALSE, quietly = TRUE)
library(plot3D, warn.conflicts = FALSE, quietly = TRUE)
library(plotly, warn.conflicts = FALSE, quietly = TRUE)
library(lattice, warn.conflicts = FALSE, quietly = TRUE)
library(purrr, warn.conflicts = FALSE, quietly = TRUE)
library(furrr, warn.conflicts = FALSE, quietly = TRUE)
library(pheatmap, warn.conflicts = FALSE, quietly = TRUE)
library(grid, warn.conflicts = FALSE, quietly = TRUE)
library(data.table, warn.conflicts = FALSE, quietly = TRUE)
library(parallel, warn.conflicts = FALSE, quietly = TRUE)
```

## 2 Import data

Import necessary data.

### 2.1 Tomato AV

Parameters defining agrivoltaic systems:

- sprop = proportion of solar in agrivoltaic system (0 to 1 in 0.5 increment.) Length = 21.
- panels = number of solar panels. Length = 16. Some sprop have same number of panels.
- al\_regs = four regions of Alabama. Northern, Central, Black Belt, Southern. Length = 4.
- array = Solar array; Sun tracking (Tracking) and non-tracking (Fixed). Length = 2.
- elecprc = electricity price (1 cents to 6 cents). Length = 6.
- height = clearance height of solar panels. 4.6 ft., 6.4 ft., and 8.2 ft. Length = 3.
- yldvar = crop yield variation (10% to 200%) = Length 21.
- yield = crop yield variation based on yldvar. (same as yldvar) = Length = 21.

Calculated results using above parameters:

- dc\_kw = DC system size (kW) See [PVWatts® Calculator](#).
- energy = total energy generated from solar system. See: [PVWatts® Calculator](#).
- capex = AV system capex per kW. See: [Capex Cost for AV](#) table 1 and table 3.
- ttlcost = total solar system cost in AV. See: [Capex Cost for AV](#) table 1 and table 3.

- anncost = annualized total cost.
- moncost = monthly total cost.
- price = crop yield price per bucket.
- eprofit = profit from electricity.

Result of Interests:

- eannprof = annualized total profit from electricity.
- emonprof = monthly total profit from electricity.
- profit = profit from crops.
- tav\_profit = total profit from solar and tomato.

```
tav_profit <- as.data.frame(
  read_feather(file = "Data/tav_profit R50.feather")
)
dim(tav_profit)
```

```
[1] 814968    29
```

### 2.1.1 Calculate tavp\_wocp

- Profit at 100% crop yield at their respective price is subtracted from tav\_profit.
- tavp\_wocp = tav\_profit - profit from 100% crop at their respective prices. This variable gives an idea where av profit stands in relation to crop profit. It helps to identify relative profitability of agrivoltaic system compared to crop only.

```
# Calculate the profit:
# Step 1: Filter the dataframe to get the unique profit values for each price when yldvar == 1
unique_profits <- unique(tav_profit[tav_profit$yldvar == 1,
                                   c("price", "profit")])

# Step 2: Create a lookup table for unique profits by price
profit_lookup <- setNames(unique_profits$profit,
                          unique_profits$price)

# Step 3: Create the new variable tavp_wocp by subtracting the unique profit from tav_profit
tav_profit$tavp_wocp <- mapply(function(
  tav_profit,
  price
```

```

) {
  profit_to_subtract <- ifelse(
    price %in%
      names(profit_lookup),
    profit_lookup[as.character(price)], 0)
  return(tav_profit - profit_to_subtract)
}, tav_profit$tav_profit, tav_profit$price)
unique_profits # 7 Prices give 7 Profits at 100% Yield.

```

```

      price    profit
11      17  5539.383
32      18  6899.383
53      19  8259.383
74      20  9619.383
95      21 10979.383
116     22 12339.383
137     23 13699.383

```

```
tav_profit[1:21,] # Sample data.
```

```

      sprop    al_regs array dc_kw panels energy elcprc elcrev height    capex
1         0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
2         0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
3         0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
4         0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
5         0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
6         0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
7         0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
8         0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
9         0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
10        0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
11        0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
12        0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
13        0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
14        0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
15        0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
16        0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
17        0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
18        0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
19        0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
20        0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
21        0 Black Belt Fixed      0      0      0  0.01      0   4.6 1.593333
      landlease ttlcost inscst recredit reap annlzcst annoftotcost monthlycost

```

1	1000	0	0	0	0	0	0	0
2	1000	0	0	0	0	0	0	0
3	1000	0	0	0	0	0	0	0
4	1000	0	0	0	0	0	0	0
5	1000	0	0	0	0	0	0	0
6	1000	0	0	0	0	0	0	0
7	1000	0	0	0	0	0	0	0
8	1000	0	0	0	0	0	0	0
9	1000	0	0	0	0	0	0	0
10	1000	0	0	0	0	0	0	0
11	1000	0	0	0	0	0	0	0
12	1000	0	0	0	0	0	0	0
13	1000	0	0	0	0	0	0	0
14	1000	0	0	0	0	0	0	0
15	1000	0	0	0	0	0	0	0
16	1000	0	0	0	0	0	0	0
17	1000	0	0	0	0	0	0	0
18	1000	0	0	0	0	0	0	0
19	1000	0	0	0	0	0	0	0
20	1000	0	0	0	0	0	0	0
21	1000	0	0	0	0	0	0	0
	opex	taxcr	anncost	eannprof	eannprofworeap	eannprofwoincentives	yldvar	yield
1	0	0	0	0	0	0	2.0	2720
2	0	0	0	0	0	0	1.9	2584
3	0	0	0	0	0	0	1.8	2448
4	0	0	0	0	0	0	1.7	2312
5	0	0	0	0	0	0	1.6	2176
6	0	0	0	0	0	0	1.5	2040
7	0	0	0	0	0	0	1.4	1904
8	0	0	0	0	0	0	1.3	1768
9	0	0	0	0	0	0	1.2	1632
10	0	0	0	0	0	0	1.1	1496
11	0	0	0	0	0	0	1.0	1360
12	0	0	0	0	0	0	0.9	1224
13	0	0	0	0	0	0	0.8	1088
14	0	0	0	0	0	0	0.7	952
15	0	0	0	0	0	0	0.6	816
16	0	0	0	0	0	0	0.5	680
17	0	0	0	0	0	0	0.4	544
18	0	0	0	0	0	0	0.3	408
19	0	0	0	0	0	0	0.2	272
20	0	0	0	0	0	0	0.1	136
21	0	0	0	0	0	0	0.0	0



	price	profit	tav_profit	tavp_wocp
1	17	21679.3826	21679.3826	16140
2	17	20065.3826	20065.3826	14526
3	17	18451.3826	18451.3826	12912
4	17	16837.3826	16837.3826	11298
5	17	15223.3826	15223.3826	9684
6	17	13609.3826	13609.3826	8070
7	17	11995.3826	11995.3826	6456
8	17	10381.3826	10381.3826	4842
9	17	8767.3826	8767.3826	3228
10	17	7153.3826	7153.3826	1614
11	17	5539.3826	5539.3826	0
12	17	3925.3826	3925.3826	-1614
13	17	2311.3826	2311.3826	-3228
14	17	697.3826	697.3826	-4842
15	17	-916.6174	-916.6174	-6456
16	17	-2530.6174	-2530.6174	-8070
17	17	-4144.6174	-4144.6174	-9684
18	17	-5758.6174	-5758.6174	-11298
19	17	-7372.6174	-7372.6174	-12912
20	17	-8986.6174	-8986.6174	-14526
21	17	-10600.6174	-10600.6174	-16140

```
rm(unique_profits); rm(profit_lookup)
```

### 2.1.2 TAV Profit > Tomato Alone

Tomato yield where tomato AV start becoming more profitable than tomato alone.

```
# Convert the data frame to a data.table for faster operations
setDT(tav_profit)

# Function to process each subset
process_subset <- function(subset) {
  subset <- subset[order(-tavp_wocp)]

  # Find the row where yield changes from positive to negative
  change_row <- which(diff(sign(subset$tavp_wocp)) == -2)[1]

  # Check if change_row is not NA
  if (!is.na(change_row)) {
    result_row <- subset[change_row, ]
  }
}
```

```

    return(result_row)
  } else {
    return(NULL)
  }
}

# Split data by unique combinations of the filtering criteria
split_data <- split(tav_profit,
                    by = c("al_regs", "array", "sprop",
                          "elcprc", "price", "height"))

# Apply the process_subset function sequentially using lapply
results <- lapply(split_data, process_subset)

# Combine all results into a single data.table
tav_be_yld <- rbindlist(results,
                        use.names = TRUE,
                        fill = TRUE) %>%
  select(al_regs, array, sprop, panels, elcprc, price,
         height, profit, yldvar, yield, tav_profit, tavp_wocp)
dim(tav_be_yld)

```

```
[1] 34027    12
```

```

# Dimension and Clean up
rm(results); rm(split_data); rm(process_subset)

```

```

write_xlsx(x = tav_be_yld,
           file = "Results/TAV Tomato Breakeven Yield R50.xlsx",
           as_table = TRUE)

```

### 2.1.3 Tax Credit for TAV

At 50% REAP, how much money should be spent as tax credit to make AV as profitable as Crops, if crop yield decreased by 50%?

```

tcc_tav_tomato_r50 <- tav_profit %>%
  filter(yldvar == 1,
         elcprc == 0.04,
         price == 20,

```

```

        sprop >= 0.1
    )
tcc_tav_tomato_r50[which.max(tcc_tav_tomato_r50$eannprofworeap),]

```

```

sprop  al_regs  array dc_kw panels energy elcprc  elcrev height  capex
<num>  <char>  <char> <num> <num> <num> <num> <num> <num> <num>
1:  0.1 Southern Tracking 28.25  59 47537  0.04 1901.48  4.6 1.733333
landlease ttlcost  incst recredit  reap annlzcst annoftotcost
<num> <num> <num> <num> <num> <num> <num>
1:  1000 55735.33 278.6767 313.7442 27857.91 2416.089 4782.678
monthlycost opex taxcr anncost eannprof eannprofworeap
<num> <num> <num> <num> <num> <num>
1:  159.1859 143.4803 1434.803 2559.57 1090.458 -1132.65
eannprofwoincentives yldvar yield price profit tav_profit tavp_wocp
<num> <num> <num> <num> <num> <num> <num>
1: -2881.198 1 1360 20 9619.383 10709.84 1090.458

```

```

cat("Minimum REAP Compensation to make TAV as profitable as Tomato: ",
    abs(max(tcc_tav_tomato_r50$eannprofworeap)) + 9619.38, fill = TRUE)

```

Minimum REAP Compensation to make TAV as profitable as Tomato: 10752.03

```

tcc_tav_tomato_r50[which.min(tcc_tav_tomato_r50$eannprofworeap),]

```

```

sprop  al_regs  array dc_kw panels energy elcprc  elcrev height capex
<num>  <char> <char> <num> <num> <num> <num> <num> <num> <num>
1:  1 Northern Fixed 423.74  885 574020  0.04 22960.8  8.2 2.33
landlease ttlcost  incst recredit  reap annlzcst annoftotcost
<num> <num> <num> <num> <num> <num> <num>
1:  1000 1123817 5619.086 3788.532 561712 48716.72 96435.34
monthlycost opex taxcr anncost eannprof eannprofworeap
<num> <num> <num> <num> <num> <num>
1:  3209.74 2893.06 28930.6 51609.78 4070.151 -40755.41
eannprofwoincentives yldvar yield price profit tav_profit tavp_wocp
<num> <num> <num> <num> <num> <num> <num>
1: -73474.54 1 1360 20 9619.383 13689.53 4070.151

```

```

cat("Maximum REAP Compensation to make TAV as profitable as Tomato: ",
    abs(min(tcc_tav_tomato_r50$eannprofworeap)) + 9619.38, fill = TRUE)

```

Maximum REAP Compensation to make TAV as profitable as Tomato: 50374.79

## 2.2 Strawberry AV

See tomato for variable descriptions.

sbav\_profit = total profit from solar and strawberry.

```
sbav_profit <- as.data.frame(  
  read_feather(file = "Data/sbav_profit R50.feather")  
)  
dim(sbav_profit)
```

```
[1] 814968    29
```

### 2.2.1 Calculate sbvp\_wocp

- Profit at 100% crop at their respective price is subtracted from sbav\_profit.
- sbavp\_wocp = sbav\_profit - profit from 100% crop at their respective prices. This variable gives an idea where av profit stands in relation to crop profit. It helps to identify relative profitability of agrivoltaic system compared to crop only.

```
# Calculate the profit:  
# Step 1: Filter the dataframe to get the unique profit values for each price when yldvar  
unique_profits <- unique(sbav_profit[sbav_profit$yldvar == 1,  
                                   c("price", "profit")])  
  
# Step 2: Create a lookup table for unique profits by price  
profit_lookup <- setNames(unique_profits$profit,  
                          unique_profits$price)  
  
# Step 3: Create the new variable sbavp_wocp by subtracting the unique profit from sqav  
sbav_profit$sbavp_wocp <- mapply(function(sbav_profit, price) {  
  profit_to_subtract <- ifelse(price %in%  
                                names(profit_lookup),  
                                profit_lookup[as.character(price)], 0)  
  return(sbav_profit - profit_to_subtract)  
}, sbav_profit$sbav_profit, sbav_profit$price)  
  
unique_profits # 7 Prices give 7 Profits at 100% Yield.
```

	price	profit
11	3	-7509.045
32	4	-4434.045

53	5	-1359.045
74	6	1715.955
95	7	4790.955
116	8	7865.955
137	9	10940.955

```
rm(unique_profits); rm(profit_lookup)
```

### 2.2.2 SBAV Profit > Strawberry Alone

Strawberry yield where strawberry AV profit start becoming more profitable than strawberry alone.

```
# Convert the data frame to a data.table for faster operations
setDT(sbav_profit)

# Function to process each subset
process_subset <- function(subset) {
  subset <- subset[order(-sbavp_wocp)]

  # Find the row where yield changes from positive to negative
  change_row <- which(diff(sign(subset$sbavp_wocp)) == -2)[1]

  # Check if change_row is not NA
  if (!is.na(change_row)) {
    result_row <- subset[change_row, ]
    return(result_row)
  } else {
    return(NULL)
  }
}

# Split data by unique combinations of the filtering criteria
split_data <- split(sbav_profit,
  by = c("al_regs", "array", "sprop",
        "elcprc", "price", "height"))

# Apply the process_subset function sequentially using lapply
results <- lapply(split_data, process_subset)

# Combine all results into a single data.table
```

```
sbav_be_yld <- rbindlist(results,
                        use.names = TRUE,
                        fill = TRUE) %>%
  select(al_regs, array, sprop, panels, elcprc, price,
         height, profit, yldvar, yield, sbav_profit, sbavp_wocp)

# Clean up
rm(results); rm(split_data); rm(process_subset)
```

```
write_xlsx(x = sbav_be_yld,
           file = "Results/SBAV Strawberry Breakeven Yield R50.xlsx",
           as.table = TRUE)
dim(sbav_be_yld)
```

### 2.2.3 Tax Credit for SBAV

```
tcc_sbav_stberry_r50 <- sbav_profit %>%
  filter(yldvar == 1,
         elcprc == 0.04,
         price == 6,
         sprop >= 0.1
        )
tcc_sbav_stberry_r50[which.max(tcc_sbav_stberry_r50$eannprofworeap)]
```

	sprop	al_regs	array	dc_kw	panels	energy	elcprc	elcrev	height	capex
	<num>	<char>	<char>	<num>	<num>	<num>	<num>	<num>	<num>	<num>
1:	0.1	Southern	Tracking	28.25	59	47537	0.04	1901.48	4.6	1.733333
	landlease	ttlcost	inscst	recredit	reap	annlzcst	annoftotcost			
	<num>	<num>	<num>	<num>	<num>	<num>	<num>			
1:	1000	55735.33	278.6767	313.7442	27857.91	2416.089		4782.678		
	monthlycost	opex	taxcr	anncost	eannprof	eannprofworeap				
	<num>	<num>	<num>	<num>	<num>	<num>				
1:	159.1859	143.4803	1434.803	2559.57	1090.458		-1132.65			
	eannprofwoincentives	yldvar	yield	price	profit	sbav_profit	sbavp_wocp			
	<num>	<num>	<num>	<num>	<num>	<num>	<num>			
1:	-2881.198	1	3075	6	1715.955	2806.413	1090.458			

```
cat("Minimum REAP Compensation to make SBAV profitable as Strawberry: ",
    abs(max(tcc_sbav_stberry_r50$eannprofworeap)) + 1715.96, fill = TRUE)
```

Minimum REAP Compensation to make SBAV profitable as Strawberry: 2848.61

```
tcc_sbav_stberry_r50[which.min(tcc_sbav_stberry_r50$eannprofworeap)]
```

```

sprop  al_regs  array  dc_kw panels energy elcprc  elcrev height capex
<num>   <char> <char> <num>  <num>  <num>  <num>   <num> <num> <num>
1:      1 Northern Fixed 423.74   885 574020   0.04 22960.8    8.2  2.33
landlease ttlcost  inscst recredit  reap annlzcst annoftotcost
      <num>   <num>   <num>   <num>  <num>   <num>   <num>
1:      1000 1123817 5619.086 3788.532 561712  48716.72    96435.34
monthlycost  opex  taxcr  anncost eannprof eannprofworeap
      <num>   <num>  <num>   <num>   <num>   <num>
1:      3209.74 2893.06 28930.6 51609.78 4070.151    -40755.41
eannprofwoincentives yldvar yield price  profit sbav_profit sbavp_wocp
      <num>   <num> <num> <num>   <num>   <num>   <num>
1:              -73474.54      1  3075      6 1715.955    5786.106    4070.151

```

```
cat("Maximum REAP Compensation to make SBAV profitable as Strawberry: ",
    abs(min(tcc_sbav_stberry_r50$eannprofworeap)) + 1715.96, fill = TRUE)
```

Maximum REAP Compensation to make SBAV profitable as Strawberry: 42471.37

### 3 Tomato AV Results

#### 3.1 tav\_profit Crosstab

```

# Define the values for each variable
# sprop <- c(0, 0.05, 0.10, 0.15, 0.20, 0.25,
#           0.30, 0.35, 0.40, 0.45, 0.50,
#           0.55, 0.60, 0.65, 0.70, 0.75,
#           0.80, 0.85, 0.90, 0.95, 1.00)
sprop <- c(0.10, 0.20, 0.30, 0.40, 0.50,
          0.60, 0.70, 0.80, 0.90, 1.00)
array <- c("Fixed", "Tracking") # Solar Array

```

```

height <- c(4.6, 6.4, 8.2) # Panel height
# yldvar <- c(0, 0.10, 0.20, 0.30, 0.40,
#           0.50, 0.60, 0.70, 0.80, 0.90, 1.00,
#           1.10, 1.20, 1.30, 1.40, 1.50, 1.60,
#           1.70, 1.80, 1.90, 2.00)
yldvar <- c(0.5, 1, 1.5)
al_regs <- c("Northern", "Central",
             "Black Belt", "Southern") # Regions AL
price <- c(17, 20, 23) # Crop Price
elcprc <- c(0.04) # Electricity Price

# Define the required columns
required_columns <- c("sprop", "array", "height",
                     "al_regs", "yldvar", "price", "elcprc")

# Check if the columns exist in tav_profit
missing_columns <- setdiff(required_columns,
                           names(tav_profit))
if (length(missing_columns) > 0) {
  stop("Missing columns in tav_profit: ",
       paste(missing_columns,
             collapse = ", "))
}

# Generate column names using reversed order of expand.grid
col_names <- apply(expand.grid(height, array, sprop), 1,
                  function(x) paste0(x[3], " ", x[2], " ", x[1]))

# Generate row names using reversed order of expand.grid (without elcprc)
row_names <- apply(expand.grid(price, yldvar, al_regs), 1,
                  function(x) paste0(x[3], " ", x[2], " ", x[1]))

# Create an empty matrix to store the results
result_matrix <- matrix(NA,
                       nrow = length(row_names),
                       ncol = length(col_names))
colnames(result_matrix) <- col_names
rownames(result_matrix) <- row_names

# Create a data frame with
# all combinations of parameters in reversed order
param_combinations <- expand.grid(elcprc = elcprc,

```



```

        price = price,
        yldvar = yldvar,
        al_regs = al_regs,
        height = height,
        array = array,
        sprop = sprop)

# Merge with tav_profit to get tav_profit values for each combination
merged_data <- merge(param_combinations,
                    tav_profit,
                    by = required_columns,
                    all.x = TRUE)

# Reshape merged_data to fill result_matrix with reversed column and row names (excluding el
merged_data$col_name <- apply(
  merged_data[, c("sprop", "array", "height")], 1,
  function(x) paste0(x[1], " ", x[2], " ", x[3]))

merged_data$row_name <- apply(
  merged_data[, c("al_regs", "yldvar", "price")], 1,
  function(x) paste0(x[1], " ", x[2], " ", x[3]))

# Fill the matrix with tav_profit values
for (i in seq_len(nrow(result_matrix))) {
  row_condition <- rownames(result_matrix)[i]
  row_data <- merged_data[merged_data$row_name == row_condition, ]

  # Ensure that there are valid matches for col_name before assignment
  col_indices <- match(row_data$col_name,
                      colnames(result_matrix))
  valid_indices <- which(!is.na(col_indices))

  if (length(valid_indices) > 0) {
    result_matrix[i, col_indices[valid_indices]] <- round(row_data$tav_profit[valid_indices])
  }
}

ct_tav_pft <- as.data.frame(result_matrix) # Table in Excel.
# Display the result matrix
rm(result_matrix); rm(sprop); rm(array); rm(height);
rm(elcprc); rm(price); rm(yldvar); rm(al_regs)

```

```
write_xlsx(x = ct_tav_pft %>%
  dplyr::mutate(Row_Names = rownames(ct_tav_pft)) %>%
  dplyr::select(Row_Names, everything()),
  file = "Results/Profit Ctab TAV R50.xlsx",
  as_table = TRUE)
dim(ct_tav_pft)
```

```
[1] 36 60
```

### 3.2 tav\_profit Heatmap

- Heatmap of 324\*30 dimension matrix
- Tomato profit.

```
# Calculate color count based on unique values, excluding zero
colorcount <- length(unique(as.vector(as.matrix(ct_tav_pft[-1]))))

# Define custom breaks to ensure zero is distinctly marked
# Calculate min and max values to define the range
min_val <- min(ct_tav_pft, na.rm = TRUE)
max_val <- max(ct_tav_pft, na.rm = TRUE)

# Create breaks that ensure zero is in the middle
breaks <- seq(min_val, max_val, length.out = colorcount)

# Separate color palettes for negative and positive values
# Negative values: Shades of red
neg_colors <- colorRampPalette(c("#890800",
                                "#FF1709",
                                "#FF8F89"))(sum(breaks < 0))

# Define the color for zero separately
zero_color <- "#FF8F89"

# Positive values: Shades of green
pos_colors <- colorRampPalette(c("#99E699",
                                "#32CD32",
                                "#196719"))(sum(breaks > 0))

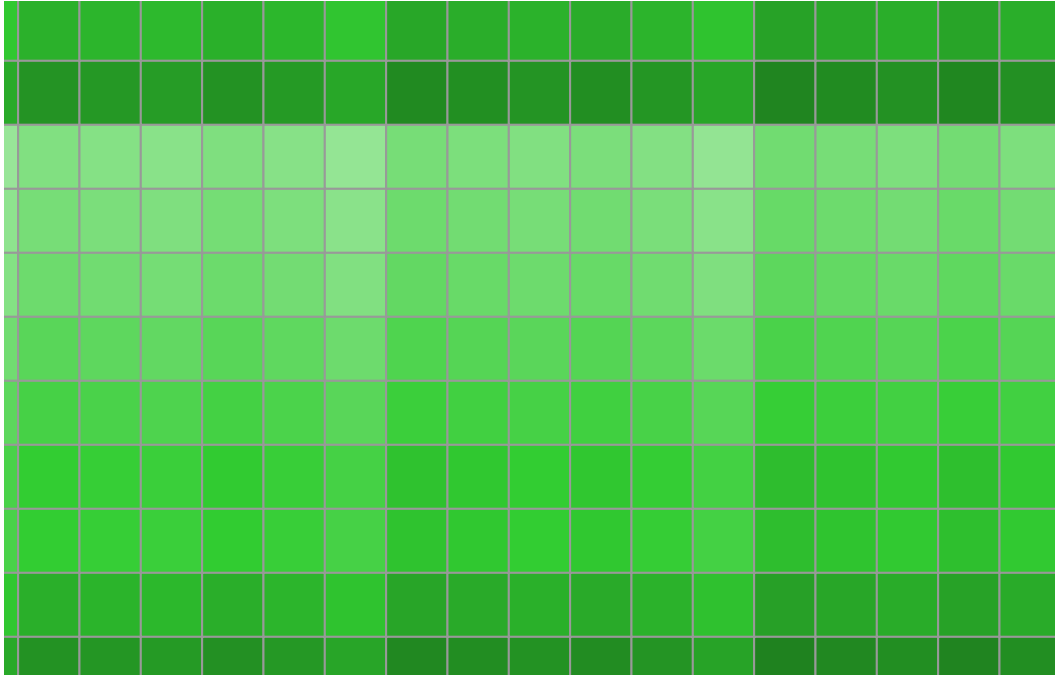
# Combine negative colors, zero, and positive colors
custom_colors <- c(neg_colors,
```

```

        zero_color,
        pos_colors)

# Generate heatmap with the custom color scheme
heatmap_plot <- pheatmap(
  (ct_tav_pft),
  clustering_distance_rows = "euclidean",
  clustering_distance_cols = "euclidean",
  clustering_method = "complete",
  angle_col = 90,
  na_col = "white",
  color = custom_colors,
  breaks = breaks,
  cutree_rows = 5,
  cutree_cols = 4,
  cluster_rows = FALSE,
  cluster_cols = FALSE,
  show_rownames = TRUE,
  show_colnames = TRUE,
  display_numbers = FALSE,
  number_format = "%.2f",
  cellheight = 24,
  cellwidth = 23,
  fontsize = 18,
  fontsize_row = 22,
  fontsize_col = 22
)

```



```
ggsave(heatmap_plot,
  height = 18,
  width = 24,
  units = "in",
  limitsize = FALSE,
  file = paste0("Plots/TAV Profits CTab R50", ".png"))
#rm(colorcount); rm(heatmap_plot)
```

### 3.3 tav\_profit manuscript

```
# Define the values for each variable
sprop <- c(0, 0.25, 0.50, 0.75, 1.00)
array <- c("Fixed", "Tracking") # Solar Array
height <- c(4.6, 6.4, 8.2) # Panel height
yldvar <- c(1) # Yield Variability
al_regs <- c("Northern", "Central", "Black Belt", "Southern")
price <- c(20) # Crop Price
elcprc <- c(0.04) # Electricity Price

# Define the required columns
required_columns <- c("sprop", "array", "height",
```

```

        "al_regs", "yldvar", "price", "elcprc")

# Check if the columns exist in tav_profit
missing_columns <- setdiff(required_columns,
                           names(tav_profit))
if (length(missing_columns) > 0) {
  stop("Missing columns in tav_profit: ",
       paste(missing_columns,
             collapse = ", "))
}

# Generate column names using reversed order of expand.grid
col_names <- apply(expand.grid(height, sprop), 1,
                  function(x) paste0(x[2], x[1]))

# Generate row names using reversed order of expand.grid
row_names <- apply(expand.grid(elcprc,
                              price,
                              yldvar,
                              al_regs,
                              array), 1,
                  function(x) paste0(x, collapse = ""))

# Create an empty matrix to store the results
result_matrix <- matrix(NA,
                       nrow = length(row_names),
                       ncol = length(col_names))
colnames(result_matrix) <- col_names
rownames(result_matrix) <- row_names

# Create a data frame with
# all combinations of parameters in reversed order
param_combinations <- expand.grid(elcprc = elcprc,
                                 price = price,
                                 yldvar = yldvar,
                                 al_regs = al_regs,
                                 height = height,
                                 array = array,
                                 sprop = sprop)

# Merge with tav_profit to get tav_profit values for each combination
merged_data <- merge(param_combinations,

```

```

        tav_profit,
        by = required_columns,
        all.x = TRUE)

# Reshape merged_data to fill result_matrix with
# reversed column and row names
merged_data$col_name <- apply(
  merged_data[, c("sprop", "height")], 1,
  function(x) paste0(x[1], x[2]))

merged_data$row_name <- apply(
  merged_data[, c("al_regs", "yldvar", "price",
                 "elcprc", "array")], 1,
  function(x) paste0(
    x[4],
    x[3],
    x[2],
    x[1],
    x[5]))

# Fill the matrix with tav_profit values
for (i in seq_len(nrow(result_matrix))) {
  row_condition <- rownames(result_matrix)[i]
  row_data <- merged_data[
    merged_data$row_name == row_condition, ]
  if (nrow(row_data) > 0) {
    result_matrix[i,
      match(row_data$col_name,
            colnames(result_matrix))] <- round(
        row_data$tav_profit, 0)
  }
}

tav_prof_man <- as.data.frame(result_matrix) # Table in Excel.
# Display the result matrix

write_xlsx(x = tav_prof_man %>%
  dplyr::mutate(Row_Names = rownames(tav_prof_man)) %>%
  dplyr::select(Row_Names, everything()),
  file = "Results/Profit TAV Manuscript R50.xlsx",
  as_table = TRUE)
# Display the result matrix
rm(result_matrix); rm(sprop); rm(array); rm(height);

```

```
rm(elcprc); rm(price); rm(yldvar); rm(al_regs)
```

### 3.4 tavp\_wocp Crosstab

- Heatmap of 324\*30 dimension matrix.
- See tav\_profit for variable naming convention.

```
# Define the values for each variable
sprop <- c(0, 0.05, 0.10, 0.15, 0.20, 0.25,
          0.30, 0.35, 0.40, 0.45, 0.50,
          0.55, 0.60, 0.65, 0.70, 0.75,
          0.80, 0.85, 0.90, 0.95, 1.00)
array <- c("Fixed", "Tracking") # Solar Array
height <- c(4.6, 6.4, 8.2) # Panel height
yldvar <- c(0, 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90,
          1.00, 1.10, 1.20, 1.30, 1.40, 1.50, 1.60, 1.70, 1.80,
          1.90, 2.00)
al_regs <- c("Northern", "Central", "Black Belt", "Southern") # Regions of AL
price <- c(17, 18, 19, 20, 21, 22, 23) # Crop Price
elcprc <- c(0.03, 0.04, 0.05) # Electricity Price

# Define the required columns
required_columns <- c("sprop", "array", "height",
                    "al_regs", "yldvar", "price", "elcprc")

# Check if the columns exist in tav_profit
missing_columns <- setdiff(required_columns,
                          names(tav_profit))
if (length(missing_columns) > 0) {
  stop("Missing columns in tavp_wocp: ",
       paste(missing_columns, collapse = ", "))
}

# Generate column names using reversed order of expand.grid
col_names <- apply(expand.grid(height, array, sprop), 1,
                  function(x) paste0(x[3], x[2], x[1]))

# Generate row names using reversed order of expand.grid
row_names <- apply(expand.grid(elcprc,
                              price,
                              yldvar,
```

```

                                al_regs), 1,
                                function(x) paste0(x, collapse = ""))

# Create an empty matrix to store the results
result_matrix <- matrix(NA, nrow = length(row_names),
                        ncol = length(col_names))
colnames(result_matrix) <- col_names
rownames(result_matrix) <- row_names

# Create a data frame with
# all combinations of parameters in reversed order
param_combinations <- expand.grid(elcprc = elcprc,
                                price = price,
                                yldvar = yldvar,
                                al_regs = al_regs,
                                height = height,
                                array = array,
                                sprop = sprop)

# Merge with tav_profit to get tav_profit values for each combination
merged_data <- merge(param_combinations,
                    tav_profit,
                    by = required_columns,
                    all.x = TRUE)

# Reshape merged_data to fill result_matrix with
# reversed column and row names
merged_data$col_name <- apply(
  merged_data[, c("sprop", "array", "height")], 1,
  function(x) paste0(x[1], x[2], x[3]))

merged_data$row_name <- apply(
  merged_data[, c("al_regs", "yldvar", "price", "elcprc")], 1,
  function(x) paste0(x[4],
                    x[3],
                    x[2],
                    x[1]))

# Fill the matrix with tav_profit values
for (i in seq_len(nrow(result_matrix))) {
  row_condition <- rownames(result_matrix)[i]
  row_data <- merged_data[

```



```

merged_data$row_name == row_condition, ]
if (nrow(row_data) > 0) {
  result_matrix[i,
    match(row_data$col_name,
          colnames(result_matrix))] <- round(
    row_data$tavp_wocp, 2)
}
}
ct_tavp_wocp <- as.data.frame(result_matrix) # Table in Excel.
dim(ct_tavp_wocp);rm(result_matrix)

```

```
[1] 1764 126
```

```

write.csv(as.data.frame(ct_tavp_wocp),
  row.names = TRUE,
  file = "Results/ct_tavp_wocp R50.csv")

```

### 3.5 tavp\_wocp Heatmap

```

colorcount = length(unique(as.vector(as.matrix(ct_tavp_wocp[-1]))))
colorcount

```

```
[1] 150092
```

```

heatmap_plot <- pheatmap(t(ct_tavp_wocp),
  #clustering_distance_rows = "correlation",
  clustering_distance_rows = "euclidean",
  clustering_distance_cols = "euclidean",
  clustering_method = "complete",
  color = colorRampPalette(c("red",
    "yellow",
    "green"))(colorcount),

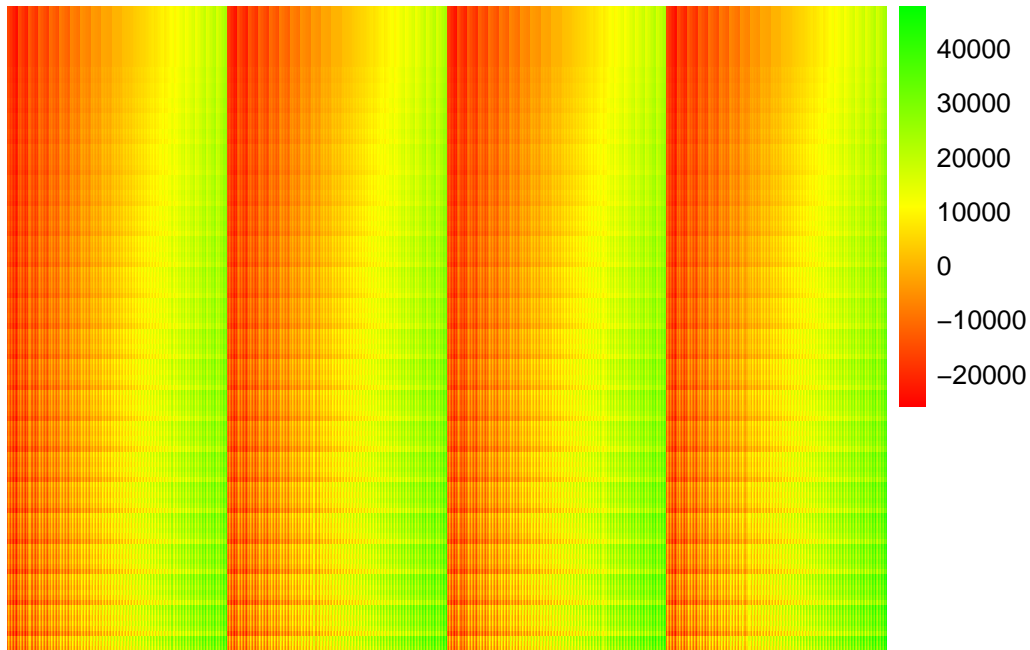
  #cutree_rows = 5,
  #cutree_cols = 4,
  cutree_rows = 5,
  cutree_cols = 4,
  cluster_rows = FALSE,
  cluster_cols = FALSE,
  show_rownames = FALSE,

```

```

show_colnames = FALSE,
display_numbers = FALSE,
number_format = "%.2f",
#cellheight = 3,
#cellwidth = 3
)

```



```

ggsave(heatmap_plot,
  height = 8,
  width = 12,
  units = "in",
  file = paste0("Plots/gp_tavp_wocp R50", ".png"))
rm(heatmap_plot); rm(colorcount)

```

### 3.6 tav\_be\_yld Crosstab

```

# Define the values for each variable
sprop <- c(0.05, 0.25, 0.50, 0.75, 0.80, 0.85, 0.90, 1)
array <- c("Fixed", "Tracking") # Solar Array
height <- c(4.6, 6.4, 8.2) # Panel height

```

```

al_regs <- c("Northern", "Central", "Black Belt", "Southern")
price <- c(17, 20, 23) # Crop Price
elcprc <- c(0.02, 0.03, 0.04) # Electricity Price
#elcprc <- c(0.04) # Electricity Price
yldvar <- c(1)
# yldvar <- c(0, 0.10, 0.20, 0.30, 0.40,
#             0.50, 0.60, 0.70, 0.80, 0.90, 1.00,
#             1.10, 1.20, 1.30, 1.40, 1.50,
#             1.60, 1.70, 1.80, 1.90, 2.00)

# Define the required columns
required_columns <- c("sprop", "array", "height",
                     "al_regs", "price", "elcprc")

# Check if the columns exist in tav_profit
missing_columns <- setdiff(required_columns,
                           names(tav_be_yld))
if (length(missing_columns) > 0) {
  stop("Missing columns in tavp_be_yld: ",
       paste(missing_columns, collapse = ", "))
}

# Generate column names using reversed order of expand.grid
col_names <- apply(expand.grid(height, array, sprop), 1,
                  function(x) paste0(x[3] , x[2] , x[1]))

# Generate row names using reversed order of expand.grid
row_names <- apply(expand.grid(elcprc,
                              price,
                              #yldvar,
                              al_regs), 1,
                  function(x) paste0(x, collapse = ""))

# Create an empty matrix to store the results
result_matrix <- matrix(NA, nrow = length(row_names),
                       ncol = length(col_names))
colnames(result_matrix) <- col_names
rownames(result_matrix) <- row_names

# Create a data frame with
# all combinations of parameters in reversed order
param_combinations <- expand.grid(elcprc = elcprc,

```

```

        price = price,
        #yldvar = yldvar,
        al_regs = al_regs,
        height = height,
        array = array,
        sprop = sprop)

# Merge with tav_be_yld to get tav_be_yld values for each combination
merged_data <- merge(param_combinations,
                     tav_be_yld,
                     by = required_columns,
                     all.x = TRUE)

# Reshape merged_data to fill result_matrix with
# reversed column and row names
merged_data$col_name <- apply(
  merged_data[, c("sprop", "array", "height")], 1,
  function(x) paste0(x[1], x[2], x[3]))

merged_data$row_name <- apply(
  merged_data[, c("al_regs", "price", "elcprc")], 1,
  function(x) paste0(x[3],
                     x[2],
                     x[1]))

# Fill the matrix with tav_profit values
for (i in seq_len(nrow(result_matrix))) {
  row_condition <- rownames(result_matrix)[i]
  row_data <- merged_data[
    merged_data$row_name == row_condition, ]
  if (nrow(row_data) > 0) {
    result_matrix[i,
                  match(row_data$col_name,
                        colnames(result_matrix))] <- round(
                      row_data$yield, 0)
  }
}

ct_tav_be_yld <- as.data.frame(result_matrix) # Table in Excel.
dim(ct_tav_be_yld); rm(result_matrix)

```

[1] 36 48

```
write.csv(as.data.frame(ct_tav_be_yld),
          row.names = TRUE,
          file = "Results/ct_tav_be_yld R50.csv")
```

### 3.7 tav\_be\_yld Heatmap

```
uniquevalue = unique(as.vector(as.matrix(ct_tav_be_yld[-1])))
uniquevalue
```

```
[1] NA 1496 1360 1224 1088 952 1768 1632 816 680 1904 544 408 272 2040
[16] 136
```

```
colorcount = length(unique(as.vector(as.matrix(ct_tav_be_yld[-1]))))
colorcount
```

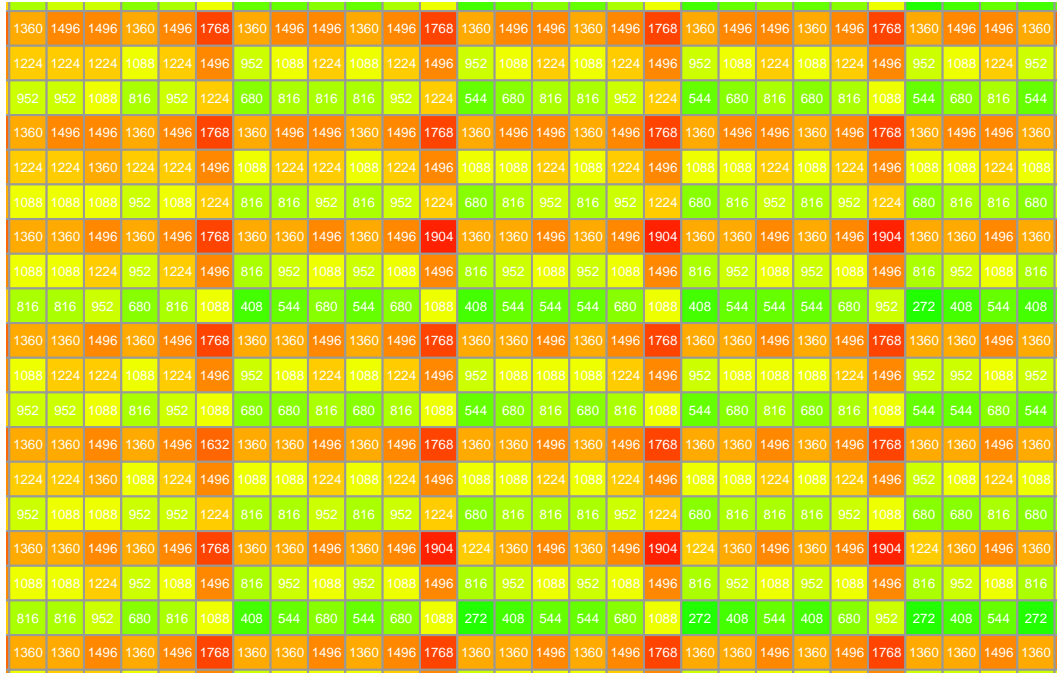
```
[1] 16
```

```
heatmap_plot <- pheatmap((ct_tav_be_yld),
  #clustering_distance_rows = "correlation",
  clustering_distance_rows = "euclidean",
  clustering_distance_cols = "euclidean",
  clustering_method = "complete",
  angle_col = 90,
  na_col = "white",
  color = colorRampPalette(
    c("green", "yellow", "red")
  )(colorcount),
  cellheight = 13,
  cellwidth = 14,
  fontsize = 12,
  fontsize_row = 12,
  fontsize_col = 12,
  number_color = "white",
  fontsize_number = 5,
  cluster_rows = FALSE,
  cluster_cols = FALSE,
  show_rownames = TRUE,
  show_colnames = TRUE,
```

```

display_numbers = TRUE,
number_format = "%.0f"
#legend_breaks = uniquevalue
)

```



```

ggsave(heatmap_plot,
  height = 8,
  width = 12,
  units = "in",
  file = paste0("Plots/gp_tav_be_yld R50", ".png"))
rm(heatmap_plot); rm(colorcount); rm(uniquevalue)

```

### 3.8 Plot Tomato Profits by Panels

You can see plot breakdown based on yield variation, crop price, and electricity price. You can see variation for all solar proportion in one facet of the chart. Each facet of the chart contain av profit three heights of solar panels, four regions of AL, two array types.

```

combinations <- expand.grid(
  yldvar = c(0, 0.1, 0.3, 0.5, 0.7, 1, 1.20, 1.5, 1.80, 2), # Yield
  price = c(17, 20, 23), # Tomato price

```

```

    elcprc = c(0.03, 0.04, 0.05) #Electricity price
  )

# Iterate over the combinations and create the plots
for (combo in seq_len(nrow(combinations))) {
  filtered_data <- tav_profit %>%
    filter(
      yldvar == combinations$yldvar[combo],
      price == combinations$price[combo],
      elcprc == combinations$elcprc[combo]
    )
  # If by panel, put panels below in color and group.
  tav_sp_plot <- ggplot(data = filtered_data,
    mapping = aes(x = al_regs,
      y = tav_profit,
      color = factor(panels),
      group = factor(panels))) +

    geom_line() +
    geom_point() +
    facet_grid(height ~ array,
      labeller = as_labeller(
        c(
          "4.6" = "4.6 ft. Height",
          "6.4" = "6.4 ft. Height",
          "8.2" = "8.2 ft. Height",
          Tracking = "Single Axis Rotation",
          Fixed = "Fixed Open Rack"
        ))) +
    guides(color = guide_legend(ncol = 1,
      reverse = TRUE)) +
    scale_x_discrete(limits = c("Northern", "Central",
      "Black Belt", "Southern"),
      labels = c("North", "Center",
        "B Belt", "South")) +
    guides(color = guide_legend(ncol = 2,
      reverse = TRUE)) +
    labs(x = "Regions of Alabama",
      y = "Profit ($)" from Tomato Agrivoltaic System",
      color = "Number of Solar \n Panels per Acre",
      title = (list(combinations[combo,]))
    ) +
    theme(strip.background = element_blank())
}

```

```

# Add horizontal line at y = 0 if y has both positive and negative values
if (min(filtered_data$tav_profit) < 0 &
    max(filtered_data$tav_profit) > 0) {
  tav_sp_plot <- tav_sp_plot +
    geom_hline(yintercept = 0,
               linewidth = 0.30,
               linetype = "dashed",
               color = "black")
}
print(combinations[combo,])
print(tav_sp_plot)
ggsave(file = paste0("Plots/tav_sp_ R50", combo, ".png"))
#break
}

```

### 3.9 Plot Tomato Profits by Yields

You can see plot breakdown based on solar proportion, crop price, and electricity price. You can see variation for all crop yield variation in one facet of the chart. Each facet of the chart contain av profit three heights of solar panels, four regions of AL, two array types.

```

combinations <- expand.grid(
  sprop = c(0, 0.25, 0.50, 0.75, 1.00), # Solar proportion
  price = c(17, 20, 23), # Tomato price
  elcprc = c(0.03, 0.04, 0.05) #Electricity price
)

# Iterate over the combinations and create the plots
for (combo in seq_len(nrow(combinations))) {
  filtered_data <- tav_profit %>%
    filter(
      sprop == combinations$sprop[combo],
      price == combinations$price[combo],
      elcprc == combinations$elcprc[combo]
    )
  # If by yield, put yield below in color and group.
  tav_yv_plot <- ggplot(data = filtered_data,
                       mapping = aes(x = al_regs,
                                      y = tav_profit,
                                      color = factor(yield),
                                      group = factor(yield))) +

```



```

geom_line() +
geom_point() +
facet_grid(height ~ array,
            labeller = as_labeller(
              c(
                "4.6" = "4.6 ft. Height",
                "6.4" = "6.4 ft. Height",
                "8.2" = "8.2 ft. Height",
                Tracking = "Single Axis Rotation",
                Fixed = "Fixed Open Rack"
              ))) +
guides(color = guide_legend(ncol = 1,
                             reverse = TRUE)) +
scale_x_discrete(limits = c("Northern", "Central",
                             "Black Belt", "Southern"),
                 labels = c("North", "Center",
                             "B Belt", "South")) +
guides(color = guide_legend(ncol = 2,
                             reverse = TRUE)) +
labs(x = "Regions of Alabama",
     y = "Profit ($)" from Tomato Agrivoltaic System",
     color = "Tomato Yield \n (25 Lb Buckets)",
     title = (list(combinations[combo,]))
) +
theme(strip.background = element_blank())
# Add horizontal line at y = 0 if y has both positive and negative values
if (min(filtered_data$tav_profit) < 0 &
    max(filtered_data$tav_profit) > 0) {
  tav_yv_plot <- tav_yv_plot +
    geom_hline(yintercept = 0,
               linewidth = 0.30,
               linetype = "dashed",
               color = "black")
}
print(combinations[combo,])
print(tav_yv_plot)
ggsave(file = paste0("Plots/tav_yv_ R50", combo, ".png"))
#break
}

```

## 4 Strawberry AV Results

### 4.1 sbav\_profit Crosstab

```
# Define the values for each variable
sprop <- c(0.10, 0.20, 0.30, 0.40, 0.50,
          0.60, 0.70, 0.80, 0.90, 1.00)
array <- c("Fixed", "Tracking")
height <- c(4.6, 6.4, 8.2)
# yldvar <- c(0, 0.10, 0.20, 0.30, 0.40, 0.50,
#           0.60, 0.70, 0.80, 0.90, 1.00,
#           1.10, 1.20, 1.30, 1.40, 1.50,
#           1.60, 1.70, 1.80, 1.90, 2.00)
yldvar <- c(0.5, 1, 1.5)
al_regs <- c("Northern", "Central",
            "Black Belt", "Southern")
price <- c(3, 6, 9)
elcprc <- c(0.04) # Electricity Price

# Define the required columns
required_columns <- c("sprop", "array", "height",
                    "al_regs", "yldvar", "price", "elcprc")

# Check if the columns exist in sbav_profit
missing_columns <- setdiff(required_columns, names(sbav_profit))
if (length(missing_columns) > 0) {
  stop("Missing columns in sbav_profit: ", paste(missing_columns, collapse = ", "))
}

# Generate column names using reversed order of expand.grid
col_names <- apply(expand.grid(height, array, sprop), 1,
                  function(x) paste0(x[3], " ", x[2], " ", x[1]))

# Generate row names using reversed order of expand.grid (without elcprc)
row_names <- apply(expand.grid(price, yldvar, al_regs), 1,
                  function(x) paste0(x[3], " ", x[2], " ", x[1]))

# Create an empty matrix to store the results
result_matrix <- matrix(NA, nrow = length(row_names), ncol = length(col_names))
colnames(result_matrix) <- col_names
rownames(result_matrix) <- row_names
```

```

# Create a data frame with all combinations of parameters in reversed order (including elcprc)
param_combinations <- expand.grid(elcprc = elcprc,
                                price = price,
                                yldvar = yldvar,
                                al_regs = al_regs,
                                height = height,
                                array = array,
                                sprop = sprop)

# Merge with sbav_profit to get sbav_profit values for each combination
merged_data <- merge(param_combinations,
                    sbav_profit,
                    by = required_columns,
                    all.x = TRUE)

# Reshape merged_data to fill result_matrix with reversed column and row names (excluding elcprc)
merged_data$col_name <- apply(
  merged_data[, c("sprop", "array", "height")], 1,
  function(x) paste0(x[1], " ", x[2], " ", x[3]))

merged_data$row_name <- apply(
  merged_data[, c("al_regs", "yldvar", "price")], 1,
  function(x) paste0(x[1], " ", x[2], " ", x[3]))

# Fill the matrix with sbav_profit values
for (i in seq_len(nrow(result_matrix))) {
  row_condition <- rownames(result_matrix)[i]
  row_data <- merged_data[merged_data$row_name == row_condition, ]

  # Ensure that there are valid matches for col_name before assignment
  col_indices <- match(row_data$col_name,
                     colnames(result_matrix))
  valid_indices <- which(!is.na(col_indices))

  if (length(valid_indices) > 0) {
    result_matrix[i, col_indices[valid_indices]] <- round(row_data$sbav_profit[valid_indices], 2)
  }
}

ct_sbav_pft <- as.data.frame(result_matrix) #Table in Excel.
# Display the result matrix
ct_sbav_pft <- as.data.frame(result_matrix) # Table in Excel.
rm(result_matrix); rm(sprop); rm(array); rm(height);

```

```
rm(elcprc); rm(price); rm(yldvar); rm(al_regs)
```

```
write_xlsx(x = ct_sbav_pft %>%  
  dplyr::mutate(Row_Names = rownames(ct_sbav_pft)) %>%  
  dplyr::select(Row_Names, everything()),  
            file = "Results/Profit Ctab SBAV R50.xlsx",  
            as_table = TRUE)  
dim(ct_sbav_pft)
```

```
[1] 36 60
```

## 4.2 sbav\_profit Heatmap

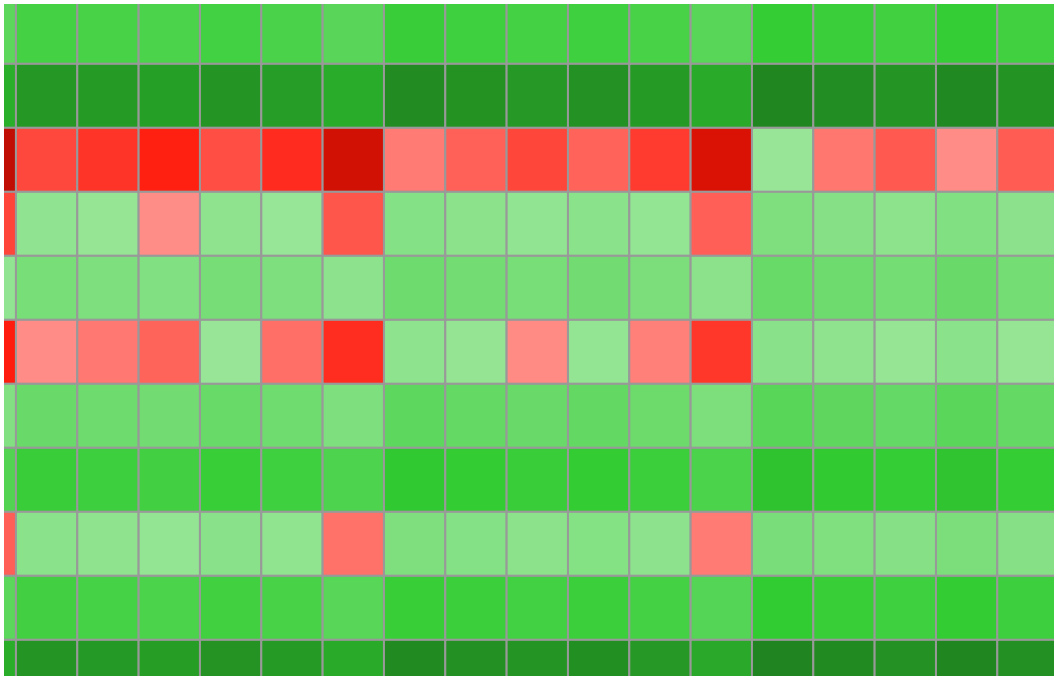
```
# Calculate color count based on unique values, excluding zero  
colorcount <- length(unique(as.vector(as.matrix(ct_sbav_pft[-1]))))  
  
# Define custom breaks to ensure zero is distinctly marked  
# Calculate min and max values to define the range  
min_val <- min(ct_sbav_pft, na.rm = TRUE)  
max_val <- max(ct_sbav_pft, na.rm = TRUE)  
  
# Create breaks that ensure zero is in the middle  
breaks <- seq(min_val, max_val, length.out = colorcount)  
  
# Separate color palettes for negative and positive values  
# Negative values: Shades of red  
neg_colors <- colorRampPalette(c("#890800",  
                                "#FF1709",  
                                "#FF8F89"))(sum(breaks < 0))  
  
# Define the color for zero separately  
zero_color <- "#FF8F89"  
  
# Positive values: Shades of green  
pos_colors <- colorRampPalette(c("#99E699",  
                                "#32CD32",  
                                "#196719"))(sum(breaks > 0))  
  
# Combine negative colors, zero, and positive colors
```

```

custom_colors <- c(neg_colors,
                  zero_color,
                  pos_colors)

# Generate heatmap with the custom color scheme
heatmap_plot <- pheatmap(
  (ct_sbav_pft),
  clustering_distance_rows = "euclidean",
  clustering_distance_cols = "euclidean",
  clustering_method = "complete",
  angle_col = 90,
  na_col = "white",
  color = custom_colors,
  breaks = breaks,
  cutree_rows = 5,
  cutree_cols = 4,
  cluster_rows = FALSE,
  cluster_cols = FALSE,
  show_rownames = TRUE,
  show_colnames = TRUE,
  display_numbers = FALSE,
  number_format = "%.2f",
  cellheight = 24,
  cellwidth = 23,
  fontsize = 18,
  fontsize_row = 22,
  fontsize_col = 22
)

```



```
ggsave(heatmap_plot,
  height = 18,
  width = 24,
  units = "in",
  limitsize = FALSE,
  file = paste0("Plots/SBAV Profits Ctab R50", ".png"))
```

### 4.3 sbav\_profit manuscript

```
# Define the values for each variable
sprop <- c(0, 0.25, 0.50, 0.75, 1.00)
array <- c("Fixed", "Tracking") # Solar Array
height <- c(4.6, 6.4, 8.2) # Panel height
yldvar <- c(1) # Yield Variability
al_regs <- c("Northern", "Central", "Black Belt", "Southern")
price <- c(6) # Crop Price
elcprc <- c(0.04) # Electricity Price

# Define the required columns
required_columns <- c("sprop", "array", "height",
  "al_regs", "yldvar", "price", "elcprc")
```

```

# Check if the columns exist in tav_profit
missing_columns <- setdiff(required_columns,
                           names(sbav_profit))
if (length(missing_columns) > 0) {
  stop("Missing columns in tav_profit: ",
       paste(missing_columns,
             collapse = ", "))
}

# Generate column names using reversed order of expand.grid
col_names <- apply(expand.grid(height, sprop), 1,
                  function(x) paste0(x[2], x[1]))

# Generate row names using reversed order of expand.grid
row_names <- apply(expand.grid(elcprc,
                              price,
                              yldvar,
                              al_regs,
                              array), 1,
                  function(x) paste0(x, collapse = ""))

# Create an empty matrix to store the results
result_matrix <- matrix(NA,
                       nrow = length(row_names),
                       ncol = length(col_names))
colnames(result_matrix) <- col_names
rownames(result_matrix) <- row_names

# Create a data frame with
# all combinations of parameters in reversed order
param_combinations <- expand.grid(elcprc = elcprc,
                                 price = price,
                                 yldvar = yldvar,
                                 al_regs = al_regs,
                                 height = height,
                                 array = array,
                                 sprop = sprop)

# Merge with tav_profit to get tav_profit values for each combination
merged_data <- merge(param_combinations,
                    sbav_profit,
                    by = required_columns,

```

```

    all.x = TRUE)

# Reshape merged_data to fill result_matrix with
# reversed column and row names
merged_data$col_name <- apply(
  merged_data[, c("sprop", "height")], 1,
  function(x) paste0(x[1], x[2]))

merged_data$row_name <- apply(
  merged_data[, c("al_regs", "yldvar", "price",
    "elcprc", "array")], 1,
  function(x) paste0(
    x[4],
    x[3],
    x[2],
    x[1],
    x[5]))

# Fill the matrix with tav_profit values
for (i in seq_len(nrow(result_matrix))) {
  row_condition <- rownames(result_matrix)[i]
  row_data <- merged_data[
    merged_data$row_name == row_condition, ]
  if (nrow(row_data) > 0) {
    result_matrix[i,
      match(row_data$col_name,
        colnames(result_matrix))] <- round(
        row_data$sbav_profit, 0)
  }
}
sbav_prof_man <- as.data.frame(result_matrix) # Table in Excel.

write_xlsx(x = sbav_prof_man %>%
  dplyr::mutate(Row_Names = rownames(sbav_prof_man)) %>%
  dplyr::select(Row_Names, everything()),
  file = "Results/Profit SBAV Manuscript R50.xlsx",
  as_table = TRUE)
# Display the result matrix
rm(result_matrix); rm(sprop); rm(array); rm(height);
rm(elcprc); rm(price); rm(yldvar); rm(al_regs)

```



## 4.4 sbavp\_wocp Crosstab

- Row naming: Electricity Price\_Crop Price\_Solar Proportion\_Alabama Regions
- Column naming: Solar Proportion\_Array Types\_Solar Panel Height.
- Solar Proportion can be converted to total number of panels.
- Only selected values from each variables are extracted for tabulation purpose.
- Values displayed in the table are profit from Strawberry AV system.

```
# Define the values for each variable
sprop <- c(0, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.50,
          0.55, 0.60, 0.65, 0.70, 0.75, 0.80, 0.85, 0.90, 0.95, 1.00)
array <- c("Fixed", "Tracking")
height <- c(4.6, 6.4, 8.2)
yldvar <- c(0, 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 1.00,
          1.10, 1.20, 1.30, 1.40, 1.50, 1.60, 1.70, 1.80, 1.90, 2.00)
al_regs <- c("Northern", "Central", "Black Belt", "Southern")
price <- c(3, 4, 5, 6, 7, 8, 9)
elcprc <- c(0.03, 0.04, 0.05)

# Define the required columns
required_columns <- c("sprop", "array", "height",
                    "al_regs", "yldvar", "price", "elcprc")

# Check if the columns exist in sbav_profit
missing_columns <- setdiff(required_columns,
                           names(sbav_profit))
if (length(missing_columns) > 0) {
  stop("Missing columns in sbav_profit: ",
       paste(missing_columns, collapse = ", "))
}

# Generate column names using reversed order of expand.grid
col_names <- apply(expand.grid(height, array, sprop), 1,
                  function(x) paste0(x[3], x[2], x[1]))

# Generate row names using reversed order of expand.grid
row_names <- apply(expand.grid(elcprc,
                              price,
                              yldvar,
                              al_regs), 1,
```

```

        function(x) paste0(x, collapse = ""))

# Create an empty matrix to store the results
result_matrix <- matrix(NA, nrow = length(row_names),
                        ncol = length(col_names))
colnames(result_matrix) <- col_names
rownames(result_matrix) <- row_names

# Create a data frame with
# all combinations of parameters in reversed order
param_combinations <- expand.grid(elcprc = elcprc,
                                price = price,
                                yldvar = yldvar,
                                al_regs = al_regs,
                                height = height,
                                array = array,
                                sprop = sprop)

# Merge with tav_profit to get sbav_profit values for each combination
merged_data <- merge(param_combinations,
                    sbav_profit,
                    by = required_columns,
                    all.x = TRUE)

# Reshape merged_data to fill result_matrix with
# reversed column and row names
merged_data$col_name <- apply(
  merged_data[, c("sprop", "array", "height")], 1,
  function(x) paste0(x[1],
                    x[2],
                    x[3]))

merged_data$row_name <- apply(
  merged_data[, c("al_regs", "yldvar", "price", "elcprc")], 1,
  function(x) paste0(x[4],
                    x[3],
                    x[2],
                    x[1]))

# Fill the matrix with sbav_profit values
for (i in seq_len(nrow(result_matrix))) {
  row_condition <- rownames(result_matrix)[i]

```

```

row_data <- merged_data[
  merged_data$row_name == row_condition, ]
if (nrow(row_data) > 0) {
  result_matrix[i,
    match(row_data$col_name,
      colnames(result_matrix))] <- round(
      row_data$sbavp_wocp, 2)
}
}
ct_sbavp_wocp <- as.data.frame(result_matrix) #Table in Excel.
rm(result_matrix)

```

```

write.csv(as.data.frame(ct_sbavp_wocp),
  row.names = TRUE,
  #col.names = TRUE,
  file = "Results/ct_sbavp_wocp R50.csv")
dim(ct_sbavp_wocp)

```

## 4.5 sbavp\_wocp Heatmap

- Heatmap of 324\*30 dimension matrix.

```

colorcount = length(unique(as.vector(as.matrix(ct_sbavp_wocp[-1]))))
colorcount

```

```
[1] 149651
```

```

heatmap_plot <- pheatmap(t(ct_sbavp_wocp),
  #clustering_distance_rows = "correlation",
  clustering_distance_rows = "euclidean",
  clustering_distance_cols = "euclidean",
  clustering_method = "complete",
  color = colorRampPalette(c("red",
    "yellow",
    "green"))(colorcount),

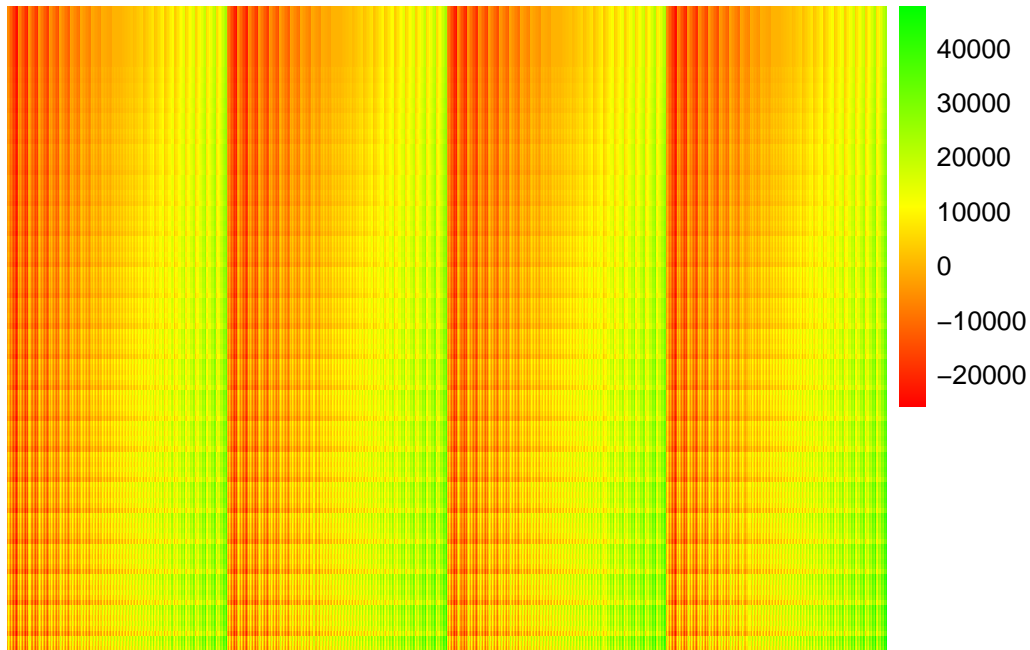
  #cutree_rows = 5,
  #cutree_cols = 4,
  cluster_rows = FALSE,
  cluster_cols = FALSE,
  show_rownames = FALSE,

```

```

show_colnames = FALSE,
display_numbers = FALSE,
number_format = "%.2f",
#cellheight = 3,
#cellwidth = 3
)

```



```

ggsave(heatmap_plot,
  height = 8,
  width = 12,
  units = "in",
  file = paste0("Plots/gp_sbavp_wocp R50", ".png"))
rm(heatmap_plot)
rm(colorcount)

```

#### 4.6 sbav\_be\_yld Crosstab

```

sprop <- c(0.05, 0.25, 0.50, 0.75, 0.80, 0.85, 0.90, 1)
array <- c("Fixed", "Tracking") # Solar Array
height <- c(4.6, 6.4, 8.2) # Panel height

```

```

al_regs <- c("Northern", "Central", "Black Belt", "Southern")
price <- c(3, 6, 9)
elcprc <- c(0.02, 0.03, 0.04) # Electricity Price
yldvar <- c(0, 0.10, 0.20, 0.30, 0.40,
           0.50, 0.60, 0.70, 0.80, 0.90, 1.00,
           1.10, 1.20, 1.30, 1.40, 1.50, 1.60,
           1.70, 1.80, 1.90, 2.00)

# Define the required columns
required_columns <- c("sprop", "array", "height",
                     "al_regs", "price", "elcprc")

# Check if the columns exist in sbav_profit
missing_columns <- setdiff(required_columns,
                           names(sbav_be_yld))
if (length(missing_columns) > 0) {
  stop("Missing columns in sbav_be_yld: ",
       paste(missing_columns, collapse = ", "))
}

# Generate column names using reversed order of expand.grid
col_names <- apply(expand.grid(height, array, sprop), 1,
                  function(x) paste0(x[3], x[2], x[1]))

# Generate row names using reversed order of expand.grid
row_names <- apply(expand.grid(elcprc,
                              price,
                              al_regs), 1,
                  function(x) paste0(x, collapse = ""))

# Create an empty matrix to store the results
result_matrix <- matrix(NA, nrow = length(row_names),
                       ncol = length(col_names))
colnames(result_matrix) <- col_names
rownames(result_matrix) <- row_names

# Create a data frame with
# all combinations of parameters in reversed order
param_combinations <- expand.grid(elcprc = elcprc,
                                 price = price,
                                 al_regs = al_regs,
                                 height = height,

```

```

        array = array,
        sprop = sprop)

# Merge with tavp_be_yld to get tavp_be_yld values for each combination
merged_data <- merge(param_combinations,
                     sbav_be_yld,
                     by = required_columns,
                     all.x = TRUE)

# Reshape merged_data to fill result_matrix with
# reversed column and row names
merged_data$col_name <- apply(
  merged_data[, c("sprop", "array", "height")], 1,
  function(x) paste0(x[1], x[2], x[3]))

merged_data$row_name <- apply(
  merged_data[, c("al_regs", "price", "elcprc")], 1,
  function(x) paste0(x[3],
                     x[2],
                     x[1]))

# Fill the matrix with sbav_profit values
for (i in seq_len(nrow(result_matrix))) {
  row_condition <- rownames(result_matrix)[i]
  row_data <- merged_data[
    merged_data$row_name == row_condition, ]
  if (nrow(row_data) > 0) {
    result_matrix[i,
                  match(row_data$col_name,
                        colnames(result_matrix))] <- round(
                      row_data$yield, 0)
  }
}
ct_sbav_be_yld <- as.data.frame(result_matrix) # Table in Excel.

write.csv(as.data.frame(ct_sbav_be_yld),
          row.names = TRUE,
          file = "Results/ct_sbav_be_yld R50.csv")
dim(ct_sbav_be_yld)

```

## 4.7 sbav\_be\_yld Heatmap

```
uniquevalue <- unique(as.vector(as.matrix(ct_sbav_be_yld[-1])))
uniquevalue
```

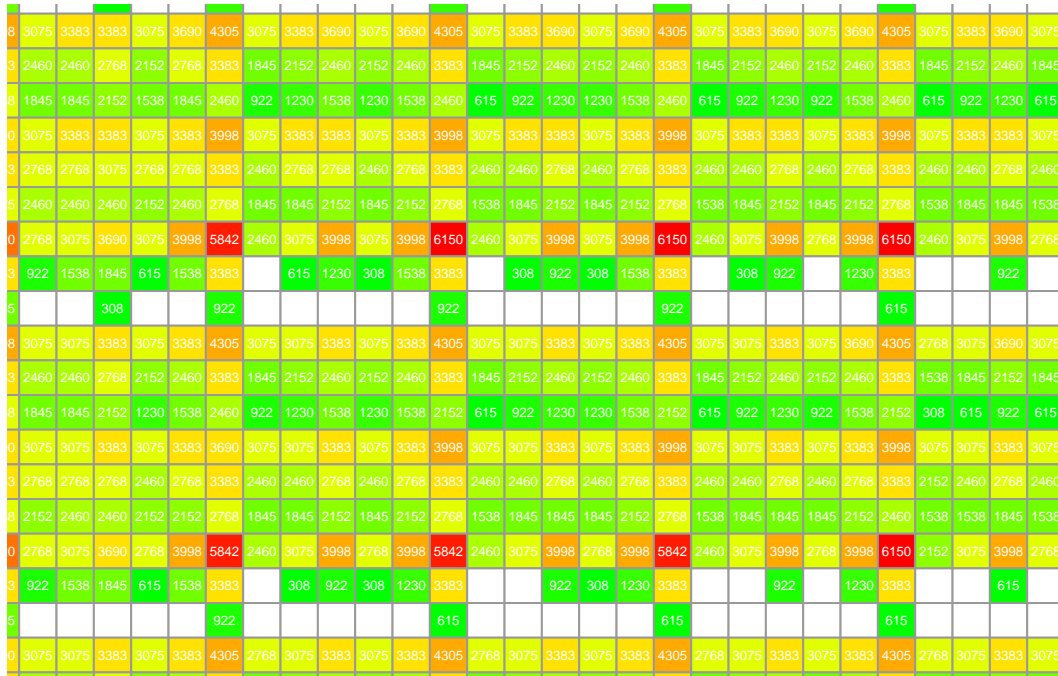
```
[1] NA 3383 2768 2152 3075 2460 1845 3998 1538 3690 308 922 615 4920 1230
[16] 4305 6150 5842 4612
```

```
colorcount <- length(unique(as.vector(as.matrix(ct_sbav_be_yld[-1])))
colorcount
```

```
[1] 19
```

```
heatmap_plot <- pheatmap((ct_sbav_be_yld),
  #clustering_distance_rows = "correlation",
  clustering_distance_rows = "euclidean",
  clustering_distance_cols = "euclidean",
  clustering_method = "complete",
  angle_col = 90,
  na_col = "white",
  color = colorRampPalette(c("green",
                             "yellow",
                             "red"))(colorcount),

  cellheight = 13,
  cellwidth = 14,
  fontsize = 12,
  fontsize_row = 12,
  fontsize_col = 12,
  number_color = "white",
  fontsize_number = 5,
  cluster_rows = FALSE,
  cluster_cols = FALSE,
  show_rownames = TRUE,
  show_colnames = TRUE,
  display_numbers = TRUE,
  number_format = "%.0f",
  legend_breaks = uniquevalue
)
```



```
ggsave(heatmap_plot,
  height = 8,
  width = 12,
  units = "in",
  file = paste0("Plots/gp_sbav_be_yld R50", ".png"))
rm(heatmap_plot); rm(colorcount); rm(uniquevalue)
```

## 4.8 Plot Strawberry Profit by Panels

You can see plot breakdown based on yield variation, crop price, and electricity price. You can see variation for all solar proportion in one facet of the chart. Each facet of the chart contain av profit three heights of solar panels, four regions of AL, two array types.

```
combinations <- expand.grid(
  yldvar = c(0, 0.1, 0.3, 0.5, 0.7, 1, 1.20, 1.5, 1.80, 2), # Yield
  price = c(3, 6, 9), # Strawberry price
  elcprc = c(0.03, 0.04, 0.05) # Electricity price
)

# Iterate over the combinations and create the plots
for (combo in seq_len(nrow(combinations))) {
  filtered_data <- sbav_profit %>%
```



```

filter(
  yldvar == combinations$yldvar[combo],
  price == combinations$price[combo],
  elcprc == combinations$elcprc[combo]
)
# If by panel, put panels below in color and group.
sbav_sp_plot <- ggplot(data = filtered_data,
  mapping = aes(x = al_regs,
    y = sbav_profit,
    color = factor(panels),
    group = factor(panels))) +

  geom_line() +
  geom_point() +
  facet_grid(height ~ array,
    labeller = as_labeller(
      c(
        "4.6" = "4.6 ft. Height",
        "6.4" = "6.4 ft. Height",
        "8.2" = "8.2 ft. Height",
        Tracking = "Single Axis Rotation",
        Fixed = "Fixed Open Rack"
      ))) +
  guides(color = guide_legend(ncol = 1,
    reverse = TRUE)) +
  scale_x_discrete(limits = c("Northern", "Central",
    "Black Belt", "Southern"),
    labels = c("North", "Center",
    "B Belt", "South")) +
  guides(color = guide_legend(ncol = 2,
    reverse = TRUE)) +
  labs(x = "Regions of Alabama",
    y = "Profit ($) from Strawberry Agrivoltaic System",
    color = "Number of Solar \n Panels per Acre",
    title = (list(combinations[combo,]))
  ) +
  theme(strip.background = element_blank())
# Add horizontal line at y = 0 if y has both positive and negative values
if (min(filtered_data$sbav_profit) < 0 &
  max(filtered_data$sbav_profit) > 0) {
  sbav_sp_plot <- sbav_sp_plot +
    geom_hline(yintercept = 0,
      linewidth = 0.30,

```

```

        linetype = "dashed",
        color = "black")
    }
    print(combinations[combo,])
    print(sbav_sp_plot)
    ggsave(file = paste0("Plots/sbav_sp_ R50", combo, ".png"))
    #break
}

```

## 4.9 Plot Strawberry Profit by Yields

You can see plot breakdown based on solar proportion, crop price, and electricity price. You can see variation for all crop yield variation in one facet of the chart. Each facet of the chart contain av profit three heights of solar panels, four regions of AL, two array types.

```

combinations <- expand.grid(
  sprop = c(0, 0.25, 0.50, 0.75, 1.00), # Solar proportion
  price = c(3, 6, 9), # Strawberry price
  elcprc = c(0.03, 0.04, 0.05) #Electricity price
)

# Iterate over the combinations and create the plots
for (combo in seq_len(nrow(combinations))) {
  filtered_data <- sbav_profit %>%
    filter(
      sprop == combinations$sprop[combo],
      price == combinations$price[combo],
      elcprc == combinations$elcprc[combo]
    )
  # If by yield, put yield below in color and group.
  sbav_yv_plot <- ggplot(data = filtered_data,
    mapping = aes(x = al_regs,
      y = sbav_profit,
      color = factor(yield),
      group = factor(yield))) +

    geom_line() +
    geom_point() +
    facet_grid(height ~ array,
      labeller = as_labeller(
        c(
          "4.6" = "4.6 ft. Height",

```

```

        "6.4" = "6.4 ft. Height",
        "8.2" = "8.2 ft. Height",
        Tracking = "Single Axis Rotation",
        Fixed = "Fixed Open Rack"
    ))) +
  guides(color = guide_legend(ncol = 1,
                              reverse = TRUE)) +
  scale_x_discrete(limits = c("Northern", "Central",
                              "Black Belt", "Southern"),
                  labels = c("North", "Center",
                              "B Belt", "South")) +
  guides(color = guide_legend(ncol = 2,
                              reverse = TRUE)) +
  labs(x = "Regions of Alabama",
       y = "Profit ($) from Strawberry Agrivoltaic System",
       color = "Strawberry Yield \n (25 Lb Buckets)",
       title = (list(combinations[combo,]))
  ) +
  theme(strip.background = element_blank())
# Add horizontal line at y = 0 if y has both positive and negative values
if (min(filtered_data$sbav_profit) < 0 &
    max(filtered_data$sbav_profit) > 0) {
  sbav_yv_plot <- sbav_yv_plot +
    geom_hline(yintercept = 0,
               linewidth = 0.30,
               linetype = "dashed",
               color = "black")
}
print(combinations[combo,])
print(sbav_yv_plot)
ggsave(file = paste0("Plots/sbav_yv_ R50", combo, ".png"))
#break
}

```