

Appendix 3. Tables of model system persistence and average annual harvest for different combinations of categorical management interventions, examples of Kendall’s Tau for various paired lists, and analysis of optimal numbers of interventions.

Tables showing all combinations of interventions, sorted by percentage persistent or average annual harvest (for both rainfall models)

Table A3.1: Percentage of runs that lasted all 60 years sorted by *percentage persistent*. Points which are Pareto optima are shown in bold text (see last section of Appendix 3 for explanation of Pareto optimization of intervention combinations). (*Historical rainfall*)

Stone Walls	Move Cows	Subsidize Cows	Crop Innovations	Preserve Forest	Store Grain	count	N	Percentage Persistent
	X	X		X	X	4	2400	81.58
	X	X	X	X	X	5	2400	79.83
X	X	X		X	X	5	2400	76.63
X	X	X	X	X	X	6	2400	75.50
	X			X	X	3	600	61.17
	X		X	X	X	4	600	60.67
	X	X			X	3	2400	58.38
X	X		X	X	X	5	600	58.33
	X	X	X		X	4	2400	57.75
X	X			X	X	4	600	57.67
X	X	X			X	4	2400	55.21
		X		X	X	3	2400	54.58
		X	X	X	X	4	2400	51.96
X	X	X	X		X	5	2400	50.71
X		X		X	X	4	2400	49.71
		X			X	2	2400	48.29
		X	X		X	3	2400	46.42
				X	X	2	600	43.17
X		X	X	X	X	5	2400	42.88
			X	X	X	3	600	41.00
X		X			X	3	2400	40.50
X				X	X	3	600	38.50
X			X	X	X	4	600	38.00
X	X				X	3	600	31.50
					X	1	600	31.33
X	X		X		X	4	600	31.00

			X		X	2	600	31.00
X		X	X		X	4	2400	30.13
X					X	2	600	28.17
	X				X	2	600	27.50
X			X		X	3	600	27.33
	X		X		X	3	600	24.00
	X	X	X	X		4	2400	8.38
X	X	X	X	X		5	2400	5.21
	X	X	X			3	2400	4.13
	X	X		X		3	2400	2.67
X	X	X	X			4	2400	2.33
		X	X	X		3	2400	1.88
X		X	X	X		4	2400	1.67
X	X	X		X		4	2400	1.33
		X	X			2	2400	0.79
	X	X				2	2400	0.63
X		X		X		3	2400	0.54
X	X	X				3	2400	0.46
		X		X		2	2400	0.33
X		X	X			3	2400	0.25
X		X				2	2400	0.13
		X				1	2400	0.08
X	X		X	X		4	600	0.00
	X		X	X		3	600	0.00
X			X	X		3	600	0.00
X	X			X		3	600	0.00
X	X		X			3	600	0.00
			X	X		2	600	0.00
	X			X		2	600	0.00
	X		X			2	600	0.00
X				X		2	600	0.00
X			X			2	600	0.00
X	X					2	600	0.00
				X		1	600	0.00
			X			1	600	0.00
	X					1	600	0.00

X						1	600	0.00
						0	600	0.00

Table A3.2: Percentage of runs that lasted all 60 years sorted by *average annual harvest*. Points which are Pareto optima are shown in bold text. (*Historical rainfall*)

Stone Walls	Move Cows	Subsidize Cows	Crop Innovations	Preserve Forest	Store Grain	count	N	Average Annual Harvest (metric tons)
X		X	X		X	4	2400	14.84
X		X	X	X	X	5	2400	14.36
		X	X		X	3	2400	14.09
X			X		X	3	600	13.91
		X	X	X	X	4	2400	13.90
			X	X	X	3	600	13.70
			X		X	2	600	13.67
X			X	X	X	4	600	13.42
X				X	X	3	600	12.46
					X	1	600	12.14
X		X			X	3	2400	11.60
X					X	2	600	11.34
		X			X	2	2400	11.34
X		X		X	X	4	2400	11.10
				X	X	2	600	11.03
		X		X	X	3	2400	11.00
	X		X		X	3	600	8.92
	X	X	X		X	4	2400	8.80
	X				X	2	600	8.02
	X	X			X	3	2400	7.08
X	X	X	X		X	5	2400	6.59
X	X		X		X	4	600	6.30
X	X	X	X	X	X	6	2400	5.25
X	X				X	3	600	5.11
X	X		X	X	X	5	600	5.01
X	X	X			X	4	2400	4.71
	X		X	X	X	4	600	4.62
	X	X				2	2400	4.56
	X			X	X	3	600	4.47

	X					1	600	4.21
	X	X	X	X	X	5	2400	4.20
	X	X	X			3	2400	4.08
	X		X			2	600	3.84
	X	X		X	X	4	2400	3.76
			X	X		2	600	3.75
X	X	X		X	X	5	2400	3.51
X	X			X	X	4	600	3.47
X			X			2	600	2.82
X	X	X	X	X		5	2400	2.68
		X	X	X		3	2400	2.66
X	X		X	X		4	600	2.63
	X	X	X	X		4	2400	2.57
X	X	X	X			4	2400	2.55
X		X	X	X		4	2400	2.54
X			X	X		3	600	2.53
X		X	X			3	2400	2.43
X	X		X			3	600	2.33
		X	X			2	2400	2.31
		X				1	2400	2.31
						0	600	2.22
X				X		2	600	2.20
X		X		X		3	2400	2.15
X	X	X		X		4	2400	2.11
X		X				2	2400	1.92
	X		X	X		3	600	1.82
			X			1	600	1.81
X	X	X				3	2400	1.79
	X			X		2	600	1.77
		X		X		2	2400	1.76
X	X					2	600	1.73
X						1	600	1.66
				X		1	600	1.48
	X	X		X		3	2400	1.24
X	X			X		3	600	0.95

Table A3.3: Percentage of runs that lasted all 60 years sorted by *percentage persistent*. Points which are Pareto optima are shown in bold text. (*High-variability rainfall*)

Stone Walls	Move Cows	Subsidize Cows	Crop Innovations	Preserve Forest	Store Grain	count	N	Percentage Persistent
X	X	X		X	X	5	2400	41.04
X	X	X	X	X	X	6	2400	40.25
X		X		X	X	4	2400	39.25
	X	X	X	X	X	5	2400	39.00
	X	X		X	X	4	2400	38.92
		X	X	X	X	4	2400	38.67
		X		X	X	3	2400	38.29
	X	X			X	3	2400	36.46
	X	X	X		X	4	2400	36.00
X	X	X			X	4	2400	34.33
		X			X	2	2400	33.46
X		X	X	X	X	5	2400	33.21
		X	X		X	3	2400	32.25
X	X	X	X		X	5	2400	31.38
X		X			X	3	2400	29.21
X		X	X		X	4	2400	24.25
X				X	X	3	600	16.00
X			X	X	X	4	600	13.67
			X	X	X	3	600	12.50
				X	X	2	600	11.17
X					X	2	600	11.00
X	X			X	X	4	600	9.50
	X			X	X	3	600	8.83
X			X		X	3	600	8.67
	X		X	X	X	4	600	8.00
			X		X	2	600	8.00
					X	1	600	7.50
X	X		X	X	X	5	600	7.33
X	X				X	3	600	4.50
X	X		X		X	4	600	4.00
	X		X		X	3	600	4.00
	X				X	2	600	2.50
	X	X	X	X		4	2400	1.83

X	X	X	X	X		5	2400	1.25
	X	X	X			3	2400	1.17
X	X	X	X			4	2400	0.92
		X	X	X		3	2400	0.79
	X	X		X		3	2400	0.71
X	X	X		X		4	2400	0.58
		X		X		2	2400	0.58
		X	X			2	2400	0.54
X		X		X		3	2400	0.50
X	X	X				3	2400	0.46
		X				1	2400	0.42
	X	X				2	2400	0.38
X		X				2	2400	0.38
X		X	X	X		4	2400	0.33
X		X	X			3	2400	0.25
X	X		X	X		4	600	0.17
	X		X	X		3	600	0.17
X			X	X		3	600	0.17
X	X			X		3	600	0.17
X	X					2	600	0.17
			X			1	600	0.17
X	X		X			3	600	0.00
			X	X		2	600	0.00
	X			X		2	600	0.00
	X		X			2	600	0.00
X				X		2	600	0.00
X			X			2	600	0.00
				X		1	600	0.00
	X					1	600	0.00
X						1	600	0.00
						0	600	0.00

Table A3.4: Percentage of runs that lasted all 60 years sorted by *average annual harvest*. Points which are Pareto optima are shown in bold text. (*High-variability rainfall*)

Stone Walls	Move Cows	Subsidize Cows	Crop Innovations	Preserve Forest	Store Grain	count	N	Average Annual Harvest (metric tons)
X		X	X		X	4	2400	14.67

X		X	X	X	X	5	2400	14.49
		X	X	X	X	4	2400	14.14
			X		X	2	600	13.91
X			X	X	X	4	600	13.90
			X	X	X	3	600	13.71
		X	X		X	3	2400	13.40
X			X		X	3	600	13.00
X				X	X	3	600	11.93
		X		X	X	3	2400	11.76
X		X			X	3	2400	11.43
		X			X	2	2400	11.13
X		X		X	X	4	2400	11.00
				X	X	2	600	10.08
X					X	2	600	10.02
					X	1	600	9.48
	X	X	X		X	4	2400	7.44
	X		X		X	3	600	7.13
	X	X			X	3	2400	6.75
	X				X	2	600	6.41
X	X	X	X		X	5	2400	5.81
X	X	X			X	4	2400	4.90
	X	X	X	X	X	5	2400	4.90
X	X		X		X	4	600	4.60
X	X	X	X	X	X	6	2400	4.38
	X	X				2	2400	4.31
	X					1	600	4.14
X			X	X		3	600	4.14
X	X				X	3	600	3.99
	X	X	X			3	2400	3.87
	X		X			2	600	3.82
X	X	X		X	X	5	2400	3.65
X	X			X	X	4	600	3.58
	X	X		X	X	4	2400	3.37
			X	X		2	600	3.28
X	X		X	X	X	5	600	3.13
	X		X	X	X	4	600	2.98

				X		1	600	2.83
X		X		X		3	2400	2.45
	X			X	X	3	600	2.42
	X	X	X	X		4	2400	2.33
						0	600	2.23
X		X	X	X		4	2400	2.16
		X				1	2400	2.15
X						1	600	2.15
X	X		X			3	600	2.05
		X		X		2	2400	2.02
X		X				2	2400	2.00
X	X					2	600	1.96
X		X	X			3	2400	1.92
X			X			2	600	1.90
X	X	X	X			4	2400	1.86
X				X		2	600	1.83
		X	X			2	2400	1.80
X	X	X	X	X		5	2400	1.80
		X	X	X		3	2400	1.71
			X			1	600	1.59
X	X	X				3	2400	1.47
	X	X		X		3	2400	1.46
	X		X	X		3	600	1.26
	X			X		2	600	1.20
X	X	X		X		4	2400	1.08
X	X			X		3	600	0.89
X	X		X	X		4	600	0.43

Examples of Kendall's Tau for different pairs of ranked lists

Table A3.5: Examples of Kendall's Tau for various pairs of 64-element ranked lists

Example	Tau
Identical lists	1.0
Each item swapped one position away: i.e. 2, 1, 4, 3, 6, 5, 8, 7... †	0.97
Each item swapped two positions away: i.e. 3, 4, 1, 2, 7, 8, 5, 6... †	0.94
Each item swapped four positions away: i.e. 5, 6, 7, 8, 1, 2, 3, 4... †	0.87
Each item swapped eight positions away †	0.75
Each item swapped 16 positions away †	0.49
<i>Our persistence and harvest rankings, high-variation rainfall scenario</i>	0.47
<i>Our persistence and harvest rankings, historical rainfall scenario</i>	0.43
Two lists of randomly selected items	~0 [§]
Each item swapped 32 positions away †	-0.02
Reversed lists	-1.0

†Compared with another list in ascending order: 1, 2, 3, 4, 5, 6, 7, 8...

§Any two randomly selected lists may not have a Kendall's Tau of 0, but the mean of lists created and compared in this way is zero.

Exploration of the optimal number of management interventions

Because each intervention represents additional financial and opportunity cost for the farmers in Mazvihwa, we summarized model persistence and average annual harvest (for biologically minimal thresholds) by the number of management interventions employed. The number of simulations in each category (e.g. zero interventions, one intervention, etc.) varies for two reasons: 1) combinatorics: there are several different ways to have three interventions, and only one way to have zero or six interventions; and 2) subsidy can be implemented four different ways, as opposed to only one way to implement other interventions, so there are more replications for subsidy. In addition, each of these possible combinations has 100 replications and is being averaged over all rainfall models, proportion crops, and spatial configurations.

We therefore report the total number of simulations used in calculating the overall proportion of models that persisted for all possible ways to have zero, one, two, three, four, five, or six interventions, and also give the average, maximum and minimum probability of persistence. For example for three interventions, there are 20 different combinations of three out of the six

interventions, and the proportion of models that persisted 60 years varies a great deal between these, depending on which interventions are included.

For the historical rainfall scenario, average persistence increased monotonically with more interventions (Table A3.6). This was also true for the high-variation rainfall scenario, though the persistence was much less in each set of combinations than in the historical scenario. For average annual harvest, there was a maximum value at four interventions, regardless of rainfall scenario, and nearly all of the combinations had lower average annual harvest in the high-variation scenario. There was a wide range in different intervention combinations, however, especially for those with many possible combinations (e.g. two, three, and four interventions) and for many interventions (five interventions also has a relatively large range within each of the scenarios and variables). The wide range is likely partly due to the averaging over the spatial configurations and proportion-crops. Note that both the persistence and annual harvest averages are similar for the 2-3 intervention categories in the historical rainfall scenario and the 3-4 intervention categories in the high-variation rainfall scenario, implying that more interventions are necessary to achieve the same level of function under higher rainfall variability.

Table A3.6: Number of interventions and impacts on model outcomes (annual average harvest and persistence for all 60 model years), summarizing tables A3.7 and A3.8.

Number of Interventions	Zero	One	Two	Three	Four	Five	Six
Number of combinations [†]	1	6	15	20	15	6	1
Number of simulations [§]	600	5400	18000	30000	27000	12600	2400
Persistence over 60 Years, Historical Rainfall Scenario							
Average	0	5.24	12	21.66	35.16	52.26	75.5
Range	NA	0–31.33	0–48.29	0–61.17	0–81.58	5.21–79.83	NA
Persistence over 60 Years, High-Variation Rainfall Scenario							
Average	0	1.35	4.54	9.75	16.69	25.53	40.25
Range	NA	0–7.5	0–33.46	0–38.29	0.17–39.25	1.25–41.04	NA
Average Annual Harvest in Metric Tons, Historical Rainfall Scenario							
Average	2.22	3.93	5.47	6.22	6.49	6.06	5.25
Range	NA	1.48–12.14	1.73–13.67	0.95–14.09	2.11–14.84	2.68–14.36	NA
Average Annual Harvest in Metric Tons, High-Variation Rainfall Scenario							
Average	2.23	3.72	5.04	5.84	5.9	5.63	4.38
Range	NA	1.59–9.48	1.2–13.91	0.89–13.71	0.43–14.67	1.8–14.49	NA

[†]The number of ways to get each combination of number of interventions, e.g. there is only one way to have all six, but six different ways to only have one. See the tables below for individual numbers for each possible combination.

[§]Each way of having each combination of interventions had many simulations associated with it (and for subsidy, there were several different ways to subsidize). This is the total number of simulations across all combinations for each number of interventions.

When ranking the individual possible combinations of interventions by the percentage of runs that persisted all 60 years, we found that using all six interventions was ranked 4th out of 64 for historical rainfall and second out of 64 for high-variability rainfall; for average annual harvest, all six interventions ranked 23rd out of 64 for historical rainfall, and 25th out of 64 for high-variability rainfall. For persistence, using no interventions at all ranked last (tied with 15 other models in the historical case and nine other models in the high-variability case), while for average annual harvest, using no interventions ranked 50th out of 64 for the historical rainfall case and 42nd out of 64 in the high-variability case. Comparing the two measures of success, the Pareto set between them (the set of intervention combinations where performing better on one measure requires doing worse on the other; see Figure A3.1 for a graphical representation) includes only cases with 3, 4, 5, and 6 interventions in the case of persistence, and only 4, 5, and 6 interventions in the case of average annual harvest. See above for the full tables of percentage persistent runs ordered by number of interventions (Table A3.1), by percentage persistent (Table A3.2), and by average annual harvest (Table A3.3) for the historical rainfall scenario, and the same for the high-variation rainfall scenario (Tables A3.4-6).

Therefore, though increasing the number of interventions did on the whole improve the persistence and average annual harvest of the model system, it mattered which combinations of interventions were used and how success was measured (short-term annual harvest or long-term persistence). Higher variability in rainfall resulted in lower success, and using no interventions at all was surprisingly beneficial for average annual harvest. For persistence, it was equally bad to use no interventions as to use 3 or 4 interventions depending on the rainfall scenario and combination of interventions. (Note that these results are averaged over all values of proportion crops and spatial configurations.)

Table A3.7: Percentage of runs that lasted all 60 years sorted by number of management interventions (for biologically minimal persistence thresholds and historical rainfall). The averages and ranges appearing in Table A3.6 were derived from this table. Points which are Pareto optima are shown in bold text.

Stone Walls	Move Cows	Subsidize Cows	Crop Innovations	Preserve Forest	Store Grain	count	N	Percentage Persistent	Average Annual Harvest (metric tons)
X	X	X	X	X	X	6	2400	75.50	5.25
X	X	X	X	X		5	2400	5.21	2.68
X		X	X	X	X	5	2400	42.88	14.36
X	X	X	X		X	5	2400	50.71	6.59
X	X		X	X	X	5	600	58.33	5.01
X	X	X		X	X	5	2400	76.63	3.51
	X	X	X	X	X	5	2400	79.83	4.20
X	X		X	X		4	600	0.00	2.63
X	X	X		X		4	2400	1.33	2.11

X		X	X	X		4	2400	1.67	2.54
X	X	X	X			4	2400	2.33	2.55
	X	X	X	X		4	2400	8.38	2.57
X		X	X		X	4	2400	30.13	14.84
X	X		X		X	4	600	31.00	6.30
X			X	X	X	4	600	38.00	13.42
X		X		X	X	4	2400	49.71	11.10
		X	X	X	X	4	2400	51.96	13.90
X	X	X			X	4	2400	55.21	4.71
X	X			X	X	4	600	57.67	3.47
	X	X	X		X	4	2400	57.75	8.80
	X		X	X	X	4	600	60.67	4.62
	X	X		X	X	4	2400	81.58	3.76
	X		X	X		3	600	0.00	1.82
X			X	X		3	600	0.00	2.53
X	X			X		3	600	0.00	0.95
X	X		X			3	600	0.00	2.33
X		X	X			3	2400	0.25	2.43
X	X	X				3	2400	0.46	1.79
X		X		X		3	2400	0.54	2.15
		X	X	X		3	2400	1.88	2.66
	X	X		X		3	2400	2.67	1.24
	X	X	X			3	2400	4.13	4.08
	X		X		X	3	600	24.00	8.92
X			X		X	3	600	27.33	13.91
X	X				X	3	600	31.50	5.11
X				X	X	3	600	38.50	12.46
X		X			X	3	2400	40.50	11.60
			X	X	X	3	600	41.00	13.70
		X	X		X	3	2400	46.42	14.09
		X		X	X	3	2400	54.58	11.00
	X	X			X	3	2400	58.38	7.08
	X			X	X	3	600	61.17	4.47
			X	X		2	600	0.00	3.75
	X			X		2	600	0.00	1.77
	X		X			2	600	0.00	3.84
X				X		2	600	0.00	2.20

X			X			2	600	0.00	2.82
X	X					2	600	0.00	1.73
X		X				2	2400	0.13	1.92
		X		X		2	2400	0.33	1.76
	X	X				2	2400	0.63	4.56
		X	X			2	2400	0.79	2.31
	X				X	2	600	27.50	8.02
X					X	2	600	28.17	11.34
			X		X	2	600	31.00	13.67
				X	X	2	600	43.17	11.03
		X			X	2	2400	48.29	11.34
				X		1	600	0.00	1.48
			X			1	600	0.00	1.81
	X					1	600	0.00	4.21
X						1	600	0.00	1.66
		X				1	2400	0.08	2.31
					X	1	600	31.33	12.14
						0	600	0.00	2.22

Table A3.8: Percentage of runs that lasted all 60 years sorted by number of management interventions (for biologically minimal persistence thresholds and high-variability rainfall). The averages and ranges appearing in Table A3.6 were derived from this table. Points which are Pareto optima are shown in bold text.

Stone Walls	Move Cows	Subsidize Cows	Crop Innovations	Preserve Forest	Store Grain	count	N	Percentage Persistent	Average Annual Harvest (metric tons)
X	X	X	X	X	X	6	2400	40.25	4.38
X	X	X		X	X	5	2400	41.04	3.65
	X	X	X	X	X	5	2400	39.00	4.90
X		X	X	X	X	5	2400	33.21	14.49
X	X	X	X		X	5	2400	31.38	5.81
X	X		X	X	X	5	600	7.33	3.13
X	X	X	X	X		5	2400	1.25	1.80
X		X		X	X	4	2400	39.25	11.00
	X	X		X	X	4	2400	38.92	3.37
		X	X	X	X	4	2400	38.67	14.14
	X	X	X		X	4	2400	36.00	7.44
X	X	X			X	4	2400	34.33	4.90

X		X	X		X	4	2400	24.25	14.67
X			X	X	X	4	600	13.67	13.90
X	X			X	X	4	600	9.50	3.58
	X		X	X	X	4	600	8.00	2.98
X	X		X		X	4	600	4.00	4.60
	X	X	X	X		4	2400	1.83	2.33
X	X	X	X			4	2400	0.92	1.86
X	X	X		X		4	2400	0.58	1.08
X		X	X	X		4	2400	0.33	2.16
X	X		X	X		4	600	0.17	0.43
		X		X	X	3	2400	38.29	11.76
	X	X			X	3	2400	36.46	6.75
		X	X		X	3	2400	32.25	13.40
X		X			X	3	2400	29.21	11.43
X				X	X	3	600	16.00	11.93
			X	X	X	3	600	12.50	13.71
	X			X	X	3	600	8.83	2.42
X			X		X	3	600	8.67	13.00
X	X				X	3	600	4.50	3.99
	X		X		X	3	600	4.00	7.13
	X	X	X			3	2400	1.17	3.87
		X	X	X		3	2400	0.79	1.71
	X	X		X		3	2400	0.71	1.46
X		X		X		3	2400	0.50	2.45
X	X	X				3	2400	0.46	1.47
X		X	X			3	2400	0.25	1.92
	X		X	X		3	600	0.17	1.26
X			X	X		3	600	0.17	4.14
X	X			X		3	600	0.17	0.89
X	X		X			3	600	0.00	2.05
		X			X	2	2400	33.46	11.13
				X	X	2	600	11.17	10.08
X					X	2	600	11.00	10.02
			X		X	2	600	8.00	13.91
	X				X	2	600	2.50	6.41
		X		X		2	2400	0.58	2.02

		X	X			2	2400	0.54	1.80
	X	X				2	2400	0.38	4.31
X		X				2	2400	0.38	2.00
X	X					2	600	0.17	1.96
			X	X		2	600	0.00	3.28
	X			X		2	600	0.00	1.20
	X		X			2	600	0.00	3.82
X				X		2	600	0.00	1.83
X			X			2	600	0.00	1.90
					X	1	600	7.50	9.48
		X				1	2400	0.42	2.15
			X			1	600	0.17	1.59
				X		1	600	0.00	2.83
	X					1	600	0.00	4.14
X						1	600	0.00	2.15
						0	600	0.00	2.23

Figure A3.1: Scatterplots showing average annual harvest and percent persistent colored by number of interventions. Optimal Pareto points are shown as triangles, on the upper left edge of the point cloud. All the Pareto optima have 3 interventions or greater for historical rainfall, and 4 interventions or greater for high-variation rainfall.

