Chapter Title: Water management across time: Dealing with too much or too little water in ancient Mesopotamia

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Water management across time: Dealing with too much or too little water in ancient Mesopotamia

Mark Altaweel

Abstract

Irrigation salinity has plagued agriculture in dry regions around the world. Simple mechanisms of fallowing allow fields to dry and remove salts from crop root zones. Drainage canals, or salt-tolerant plants that remove salts from soil layers, sometimes aid this process. This chapter explores how different fallowing strategies may have been applied to address concerns of over-irrigation that led to salinisation, while allowing farmers to produce sufficient crops so as not to under-irrigate. The chapter looks at southern Mesopotamia, for which historical and archaeological data provides information on irrigation societies from ancient to more recent periods. Results demonstrate optimal strategies for irrigation for different types of fields based on their drainage capacity. Fields that are well drained, often located along the levee crests, need shorter fallowing, such as one to two years, although longer fallow periods are required as salinisation increases. For more poorly drained areas, along levee slopes and basins, fallowing was generally longer, perhaps five years or more. Conditions of high salinity, however, may require shorter fallow periods, as fields become quickly saturated with salts.

Introduction

Managing water systems over variable time and over changing environmental conditions requires water system management to be adaptive and to be able to evolve so that given water use systems can be sustained. This is the case with irrigation systems, where in dry regions issues of salinisation are often present (Fritsch and Fitzpatrick, 1994). In ancient Mesopotamia salinisation has been identified as an issue: overuse of water resources can result in salinised fields, and underuse of irrigation in underproducing fields (Jacobsen and Adams, 1958; Jacobsen, 1982). In effect, while irrigation is necessary in southern Mesopotamia for crop production, overdependence on it can lead to diminished yields and salinised fields, while limiting it too much leads to low productivity. Scholars have also contested that mitigation of salts, in the form of sodium chloride as well as other mineral salts, would have been possible, and salinity may have not been a major concern in agriculture (Powell, 1985).

This chapter addresses cases in which irrigation agriculture is applied to a southern Mesopotamian case, using the cities and regions around Nippur and Uruk, to demonstrate how different adaptive strategies could limit salinity in cases where it might have become an impediment to irrigation agriculture. The intent is to demonstrate how a balanced use of irrigation could result in optimal strategies for different types of irrigated fields. The goal is also to demonstrate where irrigation salinity could become a serious problem, as drainage and fallowing may not allow adequate time for fields to recover. On the other hand, adaptive responses through optimal fallowing and drainage are discussed too. The object of this chapter is to demonstrate the types of strategies that could be undertaken to limit salinisation and also to adapt to environmental conditions that threaten productivity.

The chapter begins by giving historical background information about the region studied as well as about the process of salinisation; the applied methods, which include the modelling approach used, are then discussed. Within the methods, the data for the case is presented. The results of a simulation model are used to demonstrate strategies that might have been undertaken by agriculturalists in cases where salinity was a hindrance to agriculture. These include a demonstration of different fallowing strategies for three types of fields that have different qualities of drainage. Discussion of the implications of these results is presented, as well as a brief conclusion.

Background

Historical background

Periodic episodes of salinisation have been reported for southern Mesopotamia, where such salinisation has been blamed for the decline in settlement and episodes of declining agriculture spanning the Middle (*c.* 1600 BC) and Late (*c.* 1200 BC) Bronze Ages into the early second millennium AD (Butzer, 2012; Jacobsen and Adams, 1958). In fact, even throughout the twentieth century modern Iraq faced high salinity, resulting in major drainage canal projects that were intended to alleviate this (Al-Ansari et al., 2014). Although southern Mesopotamia in ancient periods was often home to some of the largest urban zones, such as Babylon and Uruk, and more recently Baghdad, overdependence on irrigation could lead to salinity in the region, because of its high temperatures and dry conditions. For evidence of salinisation, scholars have presented textual sources that record declining yields and a switch in the late third millennium BC to a greater use of barley, a more salt-tolerant grain. Although the third millennium BC is often seen as a period of widespread settlement in southern Mesopotamia, declining yields have been suggested as evidence of increased agricultural stress from salinisation (Jacobsen, 1982; Maekawa, 1974). Records of yield decline, by a third in places over the span of a few hundred years, with barley eventually making up nearly 98 per cent of the grain grown, form some of the relevant supporting data (Maekawa, 1973–4, 1984).

If we assume that some of the yield results mentioned above may reflect salinisation, we can also assume that human societies were not weak victims of their environment. Adaptive responses to increased salinity are likely in any period. The cultivation of barley is one possible example of such adaptation. However, other responses include fallowing, leaching of soils (using both natural and engineered means such as washing soils or purposely flooding fields), growing plants that absorb salts, and removing water to prevent salinity through drainage (Gibson, 1974; Jacobsen, 1982; Powell, 1985). Drainage canals are a possibility in ancient periods; they would have prevented both waterlogging and increased salinity. However, they would have required more extensive work and it is not clear if this occurred in ancient periods, or at least before late antiquity in the first millennium AD (Artzy and Hillel, 1988; Poyck, 1962). More recent studies of salinity in Iraq have shown that many mitigation strategies offer mostly temporary reprieve: soils can easily become filled with salts, or the salts are not easily removed from the soil profile once added. Often, the most effective method for removing salts from the root zone, where plant growth is most important, is simply to leave fields fallow so that salt naturally drains from the upper layers, even if it does not disappear entirely (Gibson, 1974). Short-term fallowing, however, may prove a temporary measure, as extended fallow periods may be needed to drain fields adequately. This includes multiple seasons of fallowing rather than a one-year-fallow/one-year-crop (biennial) fallow system, which is a more typical scenario in southern Mesopotamia. Balancing the right number of fallow years or cycles with rates of salinity therefore becomes a key problem for Mesopotamian agriculturalists.

Process of salinisation

Salinisation, or the addition of sodium chloride and other salt minerals to agricultural fields, is a common process in dry regions and in areas where poor drainage is present, there are high levels of salts in soils, over-irrigation is common, and a high water table exists (Chhabra, 1996; Smedema and Shiati, 2002). Capillary rise, through which the high evaporation rates common to hot regions often leave a crust of salt at the surface, and the use of salty irrigation water, are among the most common processes that add salt to plant root zones. Rainfall, if sufficient, can help to leach salts from fields. Areas that are low in slope or have poor drainage generally accumulate more salts.

In the past, fallowing was probably practised, as it allowed rain and natural drainage to remove salts from fields. Plants such as *Proserpina stephanis* and *Alhagi maurorum* were grown on fallow fields to help dry them out by diminishing capillary rise in the root zone and generally drying out subsoil layers. If salts are not removed in an agricultural yearly cycle from subsoil layers, it is possible that they will reappear the following season when irrigation is brought in and water rises through capillary action. Rapid evaporation, poor drainage, capillary action (i.e., a high water table) and a lack of sufficient rainfall to wash fields are all evident in southern Mesopotamia, making it highly susceptible to salinisation. While today salinity is a major problem in southern Iraq (i.e., southern Mesopotamia), it is assumed that similar processes occurred in the past, as the conditions for salinity present today were very likely true in different periods (Artzy and Hillel, 1988; Gibson, 1974; Jacobsen and Adams, 1958).

Methods

Applied modelling

To study the process of salinisation and methods of adaptation, a simulation model is created. This modelling method uses my earlier approach (Altaweel, 2013) to investigating salinisation, which builds on Prendergast's (1993) model of salinisation. Figure 9.1 highlights the model's agricultural steps, which integrate human intervention with a model that simulates salt change to the root zone due to irrigation. In effect, the steps represent a social-ecological modelling approach, in which human actions adapt and respond to environmental stimuli. Altaweel (2013) provides an appendix of the notation that summarises the model, which includes a site from which the code can be downloaded. The model is only summarised here, as it is available in the earlier work.

The basic model allows salt to accumulate in the root zone of agricultural areas: irrigation and rainfall add salts to fields. This accumulation is balanced by the fact that salts can be leached from soils, through human intervention or through natural washing or removal of salts. Although it is not known how human actors may have stimulated leaching, we can assume that some rate, even if minimal, occurred. Salt build-up occurs, and is measured through electric conductivity, in which decisiemens per metre (dS/m) is a common unit of measurement of salinity. Salts do not accumulate uniformly, as areas that have greater slope generally drain better. The leaching fraction and evaporation determine the rate of salts being added to the root zone. Yield is based on the effect of salt in the root zone and the type of agricultural crop (i.e., more or less resistant to salt); in applied modelling, barley, which is more resistant to salt, is used. Capillary rise is also a factor, as it brings salts to the surface and the root zone. The key decision to be made, then, is how long fields should remain fallow under conditions of irrigation, in which the water brought would lead to fields accumulating salt as it sat on fields and percolated into the root zone. Fallowing allows a period of time for salts to diminish from the root zone. However, extended fallowing can come at a cost to farmers, as they lose yield from the unproductive fields. In effect, farmers had to balance not only the amount of water, which promotes salinity, they applied to fields but also how long fields should remain in agricultural production: irrigating too much can lead to high salinity, and low irrigation results in low overall yields.

In a step-by-step manner, using Figure 9.1, the model applies an agent-based method (ABM; Bonabeau, 2002) in which agricultural agents apply rule-based agricultural mechanisms and the agents' decision focuses on fallowing activity. The first step (1) is for the farmer to decide to plant or leave a field fallow. A field left fallow becomes leached of salts during the agricultural year, while a field that is planted (2) will be irrigated. Rainfall (3) then falls (which can be shown by using a Markov chain on known rainfall patterns) during the agricultural year, bringing a small level of salts to fields as well as run-off. Irrigation (4) then occurs, which includes several sub-processes that affect root salinity. Salinity from irrigation and from rain is added to the root zone in these steps. A salinity result is produced, and fields are then harvested (5). The harvest value ranges from 0 to 1.0, where 0 represent no yield or a yield completely affected by salt, and 1.0 represents a yield not affected by salt. Farmers then decide if they will conduct extended fallowing (6), or long-term fallowing, the normal cycle being a biennial fallow. Fallowing decisions are affected by how much salt tolerance and fallow scaling a farmer should apply. Salt tolerance is how much yield reduction a farmer should accept. For instance, field yields of 0.5 and 0.4 apply to fields that give 50 and 40 per cent of their expected productivity because of the presence

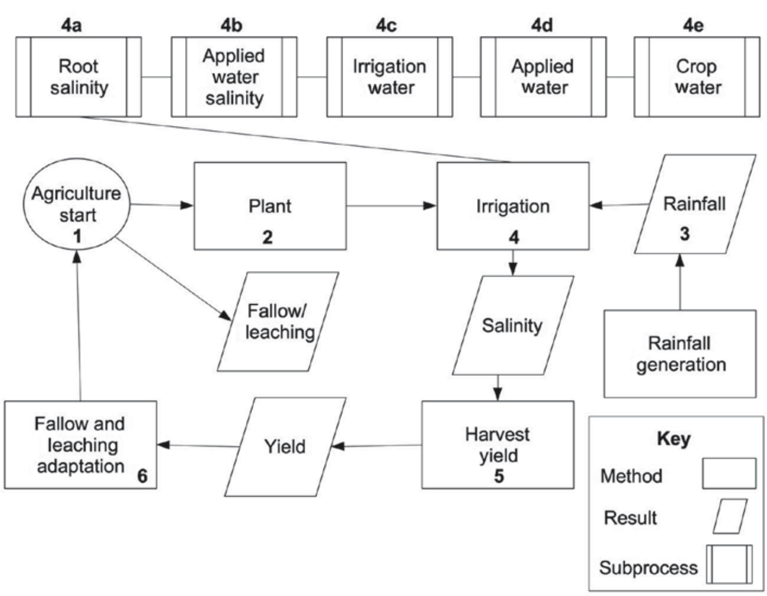

Figure 9.1 The steps applied in the model. Source: author

of salts. These values reflect what a farmer will tolerate in the productivity of fields. Fallow scaling regulates the response. If yields drop below a level tolerated by a farmer (e.g., 0.4, or 40 per cent, of the expected yield) because of the effects of salinisation, a fallow-scaling value regulates more or less years of additional fallowing. The greater the fallow-scaling value, the more time is given to fallowing, which allows fields to recover from salinity (for example through natural leaching or through built drainage channels).

Case study: Southern Mesopotamia

The data applied in the modelling presented below relates to the physical regions around Nippur and Uruk, major settlements in southern Mesopotamia during the Bronze Age (Finkbeiner, 1991; Gibson et al., 1992). The area was surveyed by Adams (1981). Sites such as Nippur and Uruk are long-lived settlements that were occupied from at least the fifth to fourth millennium BC to the early or mid first millennium AD.

Satellite data, specifically Shuttle Radar Topography Mission (SRTM; http://asterweb.jpl.nasa.gov/, accessed 3 February 2017) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER; http://asterweb.jpl.nasa.gov/, accessed 3 February 2017), has been released that can be used for terrain elevation data. This data is useful in the model discussed below, as it highlights where canal levees are evident in relation to Bronze Age sites such as Nippur and Uruk (Figure 9.2a). It also defines terrain slope, showing where potential field types might be located. Slope data and imagery distinguish three irrigated areas, classified as levee crest (LC), levee slope (LS) and basin (B) fields. Fields that are LC are relatively well-drained areas located along the banks of canals; lower clay content and coarser sediments such as silt and sand are found in such fields. Fields that are LS are less well drained, with poorer leaching of salt, and have higher clay content. They are intermediate in their location along slopes of levees; silts enable some drainage and leaching to occur. Fields that are B are the worst for drainage and leaching because of a high percentage of clay, which means these fields generally have very low slope.

Data on settlement location was obtained from Hritz (2005, 2010). For soil data, Buringh (1960) and Powers (1954) are used to reconstruct soil profiles from the region. These profiles affect leaching factors, depth of soils, and the level of the water table. The soils are generally saline-alkali in composition, although salinity is affected also by the composition of

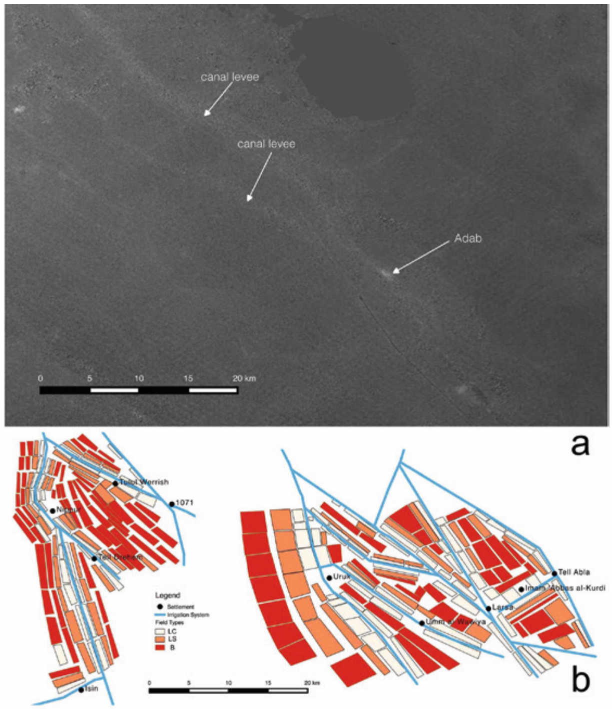

Figure 9.2 a. Canal levees, shown as light-coloured streaks, are determined using SRTM and ASTER elevation data, where slight elevation contrasts make them visible in the surrounding terrain. The ancient city of Adab (mostly a Bronze Age city) is indicated. b. Fields simulated in the region around the ancient sites of Nippur and Uruk. The field types simulated are levee crest (LC), levee slope (LS) and basin (B). Source: author

the clays, silts and sands present. The thickness of soil layers, along with electric conductivity (EC), for the water table is also present in other studies used here (see Jorenush and Sepaskhah, 2003). Capillary movement of water is a significant factor in southern Iraq (Barica, 1972; Goudie, 203) because the water table is high. Dry conditions, in which irrigation would be depended on for agriculture, can be assumed for many periods; data can be obtained from rainfall stations in southern Iraq for the period between 1930 and 1955 (NOAA, 2017). Rainfall patterns can be varied using a Markov chain algorithm, although generally conditions stay fairly stable where rainfall falls mainly from autumn to spring and summers are dry. Evaporation is an important factor; studies by Al-Khafaf et al. (1989) can be used to estimate what the rates are for the hot and dry conditions that would be found in southern Iraq/Mesopotamia.

Table 9.1 Types of model inputs used in scenarios and their data sources

Data input	Data source
Pan evaporation/coefficient (E_p)	Al-Khafaf et al., 1989
Empirical coefficient (*K*)	Al-Nakshabandi and Kijne, 1974
Rainfall salinity (C_r)	Prendergast, 1993
Irrigation salinity (C_w)	Kiani and Mirlatifi, 2012; Prendergast, 1993
Threshold salinity (*A*)	Barrett-Lennard, 2002; FAO, 2017
Crop coefficient (K_c)	Araya et al., 2011
Soil typology	Powers, 1954; Buringh, 1960
Fallow seasons (*FA*)	Jacobsen and Adams, 1958
Yield (*Y*)	Barrett-Lennard, 2002; FAO, 2017
Soil layer (*d*)	Barica, 1972; Dieleman, 1977
Water table conductivity (EC_{wt})	Jorenush and Sepaskhah, 2003
Yield response factor (K_y)	Doorenbos and Kassam, 1979
Leaching fraction (*LF*)	van Hoorn, 1981; Lyle et al., 1986
Capillary rise (*J*)	Goudie, 2003; Jorenush and Sepaskhah, 2003
Landscape and settlements	Adams and Nissen, 1972; Adams, 1981; Hritz, 2005; USGS, 2017
Rainfall (*R*)	NOAA, 2017
Percentage yield reduction (*B*)	FAO, 2017
Salt tolerance (*ST*)	
Fallow season scaling (*T*)	Gibson, 1974; Poyck, 1962
Leaching efficiency (E_l)	van Hoorn, 1981

Certainly some yield loss could be tolerated; however, allowing too much salt to be introduced could do long-term damage to fields. Extended fallowing outside the normal biennial crop cycle was probably applied as a primary means of mitigating salinisation (Gibson, 1974; Poyck, 1962). For modelling scenarios, barley is the crop used, as it is more salt-tolerant (Jacobsen, 1982). Planting occurs in the autumn, and irrigation primarily in the spring, when more water is available. Other variables in the model are the salinity threshold and the percentage yield reduction related to barley, which can be found in FAO tables (Tanji and Kielen, 2002: Annex 1). The model variables used, and their information sources, are listed in Table 9.1; they are similar to Altaweel (2013: Table 1). Figure 9.2b indicates the settlements and fields modelled in scenarios that use physical data gathered from the cited sources.

Results

Table 9.2 lists the variables and inputs, including their ranges where relevant, used in scenarios. Simulations were executed for 100 years, with multiple runs for parameter settings averaged in the results given.

Scenario one

The first scenario investigates conditions in which irrigation salinity is low, at a value of 1.0 dS/m (Al-Khafaf et al., 1990). The scenario demonstrates the effects of moderate salinity levels on agricultural output under conditions of no fallowing and biennial fallow. While in this case salinity conditions are low, salts do build up in soils without the aid of any fallowing. Figure 9.3 shows how field conditions change over time as fallowing is removed altogether from modelling runs. In effect, all field types are affected by salinisation (Figure 9.3a), although LC fields are the least affected and the influence of salinity generally occurs later. Overall,

Table 9.2 Input values for parameters. From left to right, LC-, LS- and B-type fields' input are indicated in columns where three data inputs are present.

Variable	Value	σ
E_p	1.1 m	0.2 m
K	0.6	
C_r	0.008 dS/m	
C_w	1.0 dS/m	
A	8.0 dS/m	
K_c	0.83	0.075
FA	1	
Y	1	
d	5	
$ECwt$	2.0 dS/m	
K_y	1	0.05
LF	0.20/0.175/0.10 m	0.05/0.04/0.03 m
J	0.35/0.50/0.70 m	0.075/0.125/0.175 m
R	see NOAA 2012 tables	
B	5.0 % per dS/m-1	
ST	0.1–1.0	
T	1–60	
E_l	0.40/0.35/0.30	

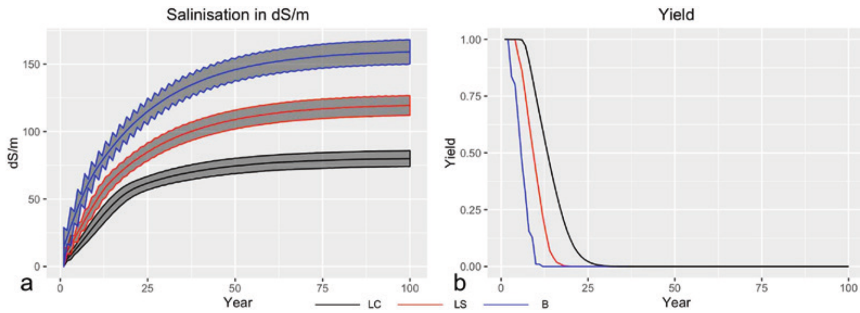

Figure 9.3 a. Salinisation and b. yield for fields. Shaded areas indicate one standard deviation from the mean result. Source: author

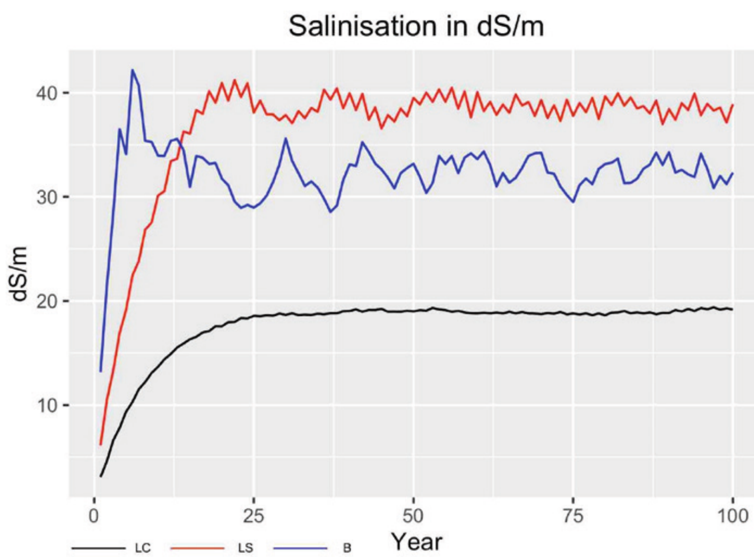

Figure 9.4 Fallowing helps to stabilise salinity in fields, as demonstrated here. Source: author

however, yields drop rapidly (Figure 9.3b), and after between 5 and 20 years all field types are almost completely affected by salinisation. In effect, yield reaches 0 (or is 100 per cent affected by salinisation) during that time because fields cannot fully drain salts as yearly irrigation is added.

Once biennial fallowing is enabled, however, salinity becomes more balanced or stable (Figure 9.4). In cases where irrigation salinity is low, minimal fallowing may be needed. Fallowing can bring about a salt balance in fields, since it gives adequate time for the natural removal of salts: salt might be present but overall salinity is lower and yields are more moderately affected. Scenario two demonstrates how such yields are affected and what the optimal responses are to enable improved overall yield results.

Scenario two

As the first scenario demonstrated, absence of fallow adjustments lead to overly saline fields, while biennial fallowing helps lead to a salt balance. This scenario addresses how farmers could adapt to optimise their production and at what levels of irrigation they can produce the best yields for given fields. Regular biennial fallowing is now implemented along with extended fallowing to optimise fields. Farmers can add additional fallow years to allow irrigation water to drain further from fields. However, farmers have to decide how much water to add or allow on their fields over a given time, because over- or under-fallowing can result in lost production. Figure 9.5a–c indicate what values of salt tolerance and fallow scaling allow the highest total yield, that is, yield over time, at the end of 100-year simulations. Figure 9.5d–f show the fallow years required for different salt tolerance and fallow-scaling values in simulations. Results stabilise (that is, an equilibrium is reached) by the end of simulations, as demonstrated in Figure 9.4, allowing for the effects of the parameters to be measured and indicated in Figure 9.5.

From these results, it is evident that different types of fields require different adaptive responses. Levee crest fields, that is, those that are better drained, have the best yields when salt tolerance is at 0.35, 0.45, 0.75 and 0.85 (Figure 9.5a), and fallow scaling, which controls how long fallow periods should be, ranges between 5 and 10. What this means is that some salinisation should be tolerated, specifically at levels that lead to yield reduction to 0.35, 0.45, 0.75 and 0.85 levels. However, this means that shorter fallow periods are better (Figures 9.5d, 9.6). In fact, fallow was only about one year in the best yield results, which is close to the normal biannual cycle with no additional years of fallowing. For LS fields, a different pattern is evident, as these fields are not as well drained. In these fields, a lower tolerance of salinity is required, and the best results were at 0.95 for salt tolerance (Figure 9.5b). Rather than too much salt, only minimal salt should be allowed. Fallow scaling is mostly low, at ranges of 5–10, although some of the better results also had high fallow scaling (60–65). This means that responses should generally have low levels of tolerance of the salt that affects yields (at 0.95 or 95 per cent

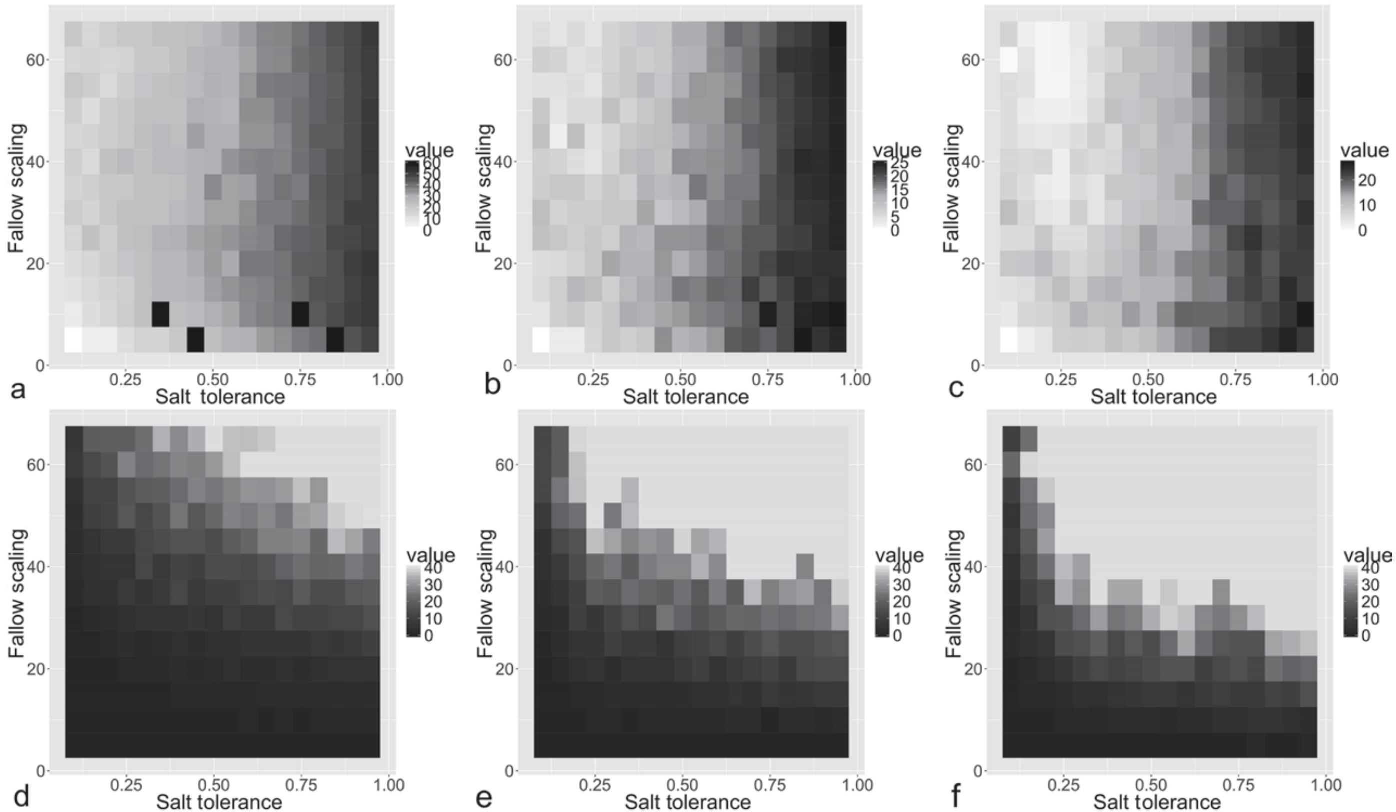

Figure 9.5 Results demonstrating yield (a–c) and fallow years (d–f) for different field types (LC (a and d), LS (b and e), and B (c and f) fields). Source: author

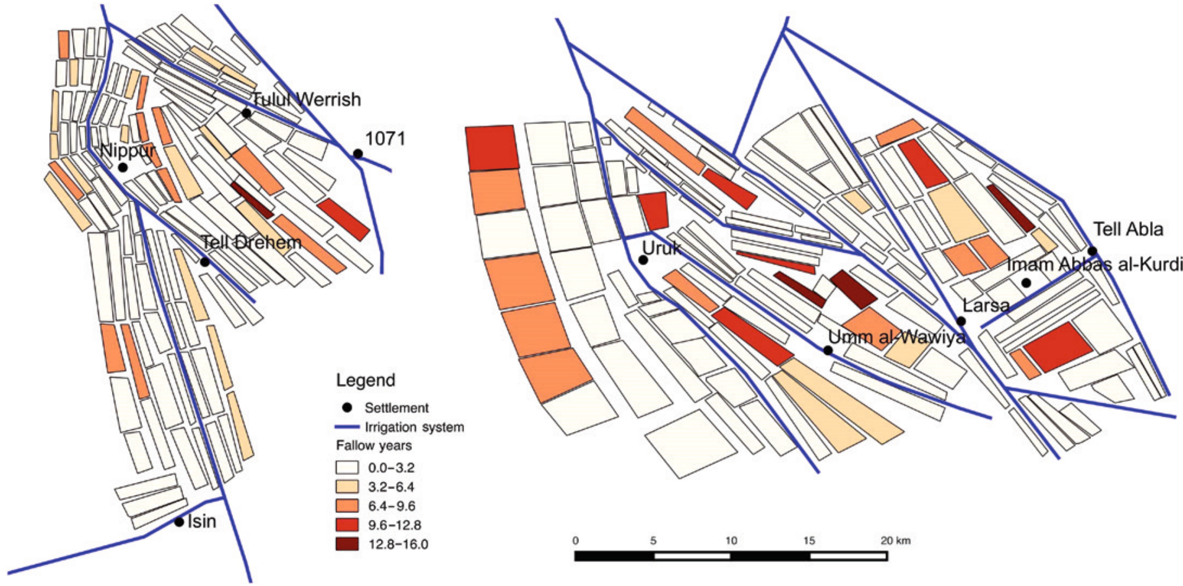

Figure 9.6 Fallow-year values for different field systems in the modelled regions. Results reflect the best adaptive salt tolerance and fallow-scaling values for LC fields; other field types are also shown. In this case, B fields show 3.2 or more fallow years.
Source: author

of expected yield), but the responses for fallowing can vary from short to longer periods. Short fallow has the benefit of putting fields back into production more quickly, while longer fallow allows higher-producing fields to recover for each year of production. Overall, the number of fallow years that gave the best results ranged from 1.02 to 3.4 (Figure 9.5e). In other words, some extra fallowing is required to improve overall yields from the normal biennial cycle. For B fields, which were the worst-draining, salt tolerance was comparable to LS fields, at 0.9–0.95 (Figure 9.5c), for the best overall yields, with fallow-scaling values also being comparable to LS fields. As for overall fallow years, the results showed that 1.7–4 years of fallow led to the best yields (Figure 9.5f).

Increasing the salinisation to 4.0 dS/m begins to affect which strategies and adaptations were more suitable for farmers who wished to increase their yields. As LC fields became more saline, and salinity increased more rapidly, salt tolerance at 0.95 and fallow scaling between 40 and 65 now became preferable (Figure 9.7a). In other words, lower tolerance of salt and longer fallowing were preferred. In this case, all the best yields required more than 4 years of fallow (Figure 9.7d). The effect of increased salinisation meant that LS fields were more similar to LC fields, where salt tolerance at 0.95 was required, although longer or shorter fallow periods led to comparable results, where fallow scaling ranged between 10 and 60 for the best yield results (Figure 9.7b). Fallow years increased to more than 5 years in the best yield results observed (Figure 9.7e). For B fields (Figure 9.7c), the results varied more. Salt tolerance at 0.95, that is, yields being 0.95 affected by salts, as with other field types, could be a beneficial strategy. However, lower salt tolerance, at 0.3 and 0.1, led to greater yield. Mostly, lower fallow scaling (5–10), that is, the mechanism controlling fallow times, was needed to create better yields for this field type. In effect, fallow periods were shorter (Figure 9.7f) for the higher-yielding salt tolerance and fallow-scaling values. The best resulting yields ranged from 1.36 and 2.23 fallow years. The reason for this is that in the basins fields became salty very quickly, which meant that long fallow periods gave little advantage. Longer fallow periods would allow the salts to drain, but the yield during that time would be very low. Tolerating higher levels of salt, and having shorter fallow periods, was better for these poorly-drained fields.

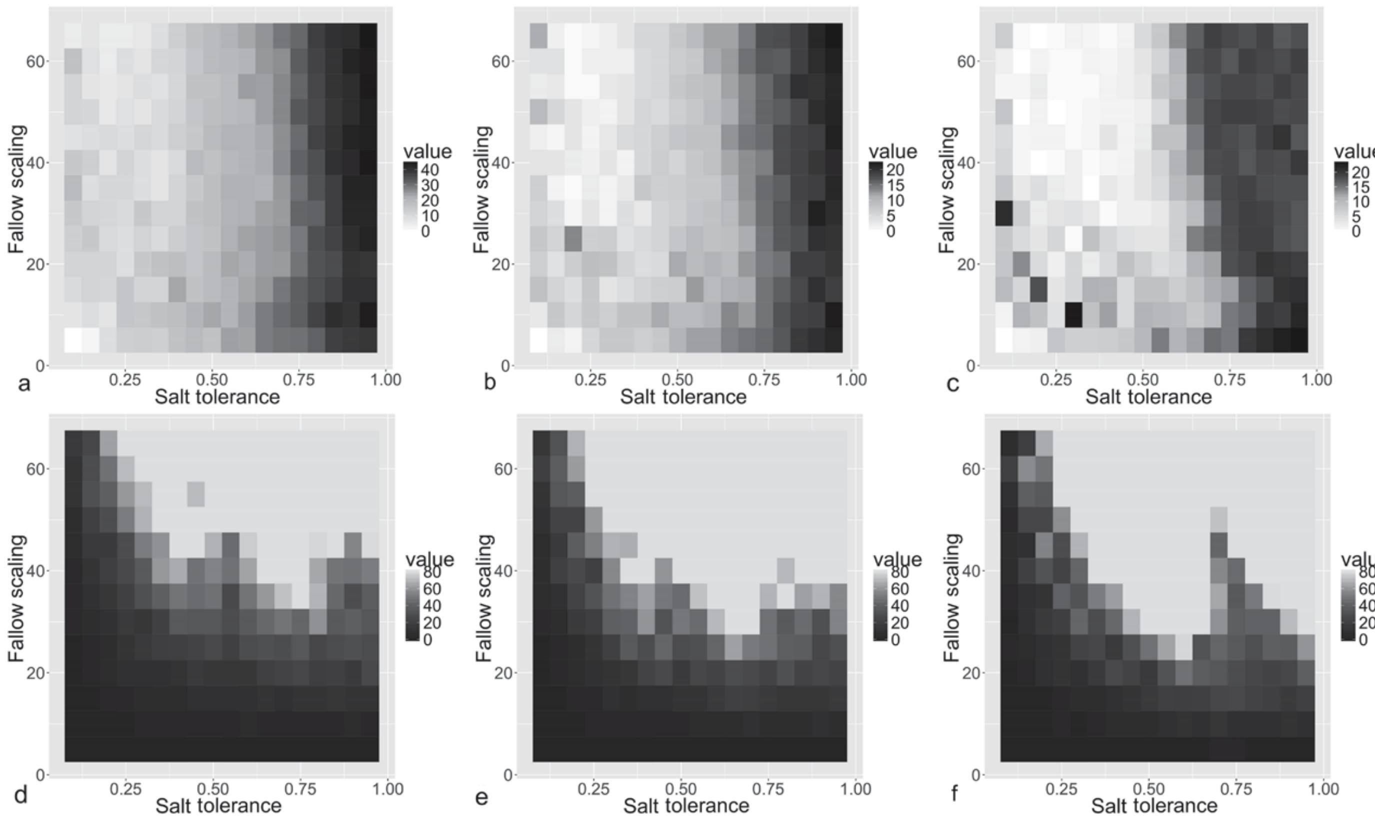

Figure 9.7 Results demonstrating yield (a–c) and fallow years (d–f) for different field types (LC (a and d), LS (b and e) and B (c and f) fields) when irrigation salinity is increased to 4 dS/m. Source: author

Discussion

The scenarios modelled above indicate that progressive salinisation can be a significant problem for agricultural fields even at low irrigation salinity (1.0 dS/m), without any human intervention. Adaptive changes, including leaching and fallowing fields, can have beneficial results. For relatively well-drained fields, such as LC fields, biannual fallow is generally sufficient, particularly if some level of tolerance of salt in fields is accepted (e.g., 0.35–0.85). However, for fields that are less well or poorly drained (LS and B), progressive salinisation can build even in cases where multi-year fallow is evident and when salinity is relatively low. For optimal yields, multi-year fallow is needed for fields that are poorly drained, ranging from 1 to 4 years (1.02–3.4 for LS and 1.7–4 for B), with light tolerance of salt on fields (e.g., 0.9–0.95).

Where salinity is increased to more moderate and greater levels, such as where the climate becomes drier (e.g., 4.0 dS/m), irrigation salinity becomes a longer-term problem even for well-drained fields such as LC. A different strategy might be required, which tolerates only very limited levels of salt, at around 0.95, and follows a more vigorous fallowing regime of up to 4 years. For LS fields a similar strategy might be required, but 5 or more years might be necessary for better yields. Interestingly, for the worst-drained fields (B), shorter fallow periods (1.36–2.23 years) are needed to limit higher levels of salinity because salinity occurs more rapidly, negating the benefits of long-term fallow. In effect, more frequent cropping and irrigation to optimise these poorly-drained fields are a better strategy.

Overall, in scenarios of low salinity, well-drained fields should be allowed to tolerate moderate levels of salt. In the absence of fieldwork or empirical evidence from the past, this chapter suggests that this may have been the practice in cases such as Bronze Age Mesopotamia. For less well-drained fields, multi-year fallowing was required. If the salinity in irrigation water increases, longer fallowing is needed in even the best-drained fields. On the other hand, poorly-drained fields are so determinately affected that the best strategy is to limit fallow years and crop, thus irrigate, more frequently. Given that B fields often showed high salinity, the outputs suggest that such places may have been avoided for agriculture. These regions could have been useful for providing reeds, natural food sources (e.g., waterfowl) and other resources (Renger, 2007), whereas irrigation agriculture may have been too costly in relation to its benefits.

Conclusion

The chapter demonstrates issues of salinisation and methods for mitigating its effects on different agricultural fields in Mesopotamia. While even mild levels of salinisation can have detrimental effects on crop yields, mitigation strategies, including biennial and extended fallowing, can minimise its effects. The results have helped to show how frequently field types could be irrigated in relation to the amount of time needed for fallowing and the leaching of field salts. They suggest that moderate levels of salinisation can be tolerated by settlements that depend on irrigation agriculture, so long as many of the fields that settlements depend on are relatively well drained. However, more substantial irrigation salinity, at levels of 4.0 dS/m or more, are likely to put greater stress on agriculturalists, as many fields, including well-drained ones, will need more extended fallowing,.

Balancing water input into fields is not an easy task, as drainage and the salinity levels of irrigation itself affect the optimal fallow and irrigation periods. Future avenues of research could investigate how irrigation practices in different regions compare to those in Mesopotamia, where climate and field types both strongly affect salinisation. Field testing results, and investigation of whether archaeological or textual evidence indicates the use of mitigation strategies, could be effective in demonstrating how significant a problem salinisation was. What is presented here is a guide to what we should expect from field systems if salinisation was a major threat, as past research has suggested. These results could be applied to Bronze Age Mesopotamia, where salinity may have been a long-term problem. Results demonstrate conditions in which salinity becomes a greater problem, such as increased aridity and the presence of salt in the water used for irrigation.

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