Appendix C: Land-use demand

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The demand for specific types of land use was simulated based on quantitative palaeodemographic data (see Appendix A) and spatial 'rules' defined by De Kleijn et al. (accepted).

Demands for food producing land

Table C.1 | *Overview of the assumptions used to calculate the land-use demands of rural settlements in AD 40, AD 70, and AD 140 based on Van Dinter et al. (2014). Since the new PLUS covers the complete first millennium, settlement sizes (i.e. population numbers) were derived using the approach outlined in Appendix A and adapted per ABR subperiod. We assume that kCal requirements and production remained stable during the investigated periods. See De Kleijn et al,* (*accepted*) f*or a more detailed description of the manner in which these data were converted in the Past Land-Use Scanner (PLUS)*

Demand for food (general)
Settlement sizes (see: palaeodemographic reconstructions; Appendix A)
An adult person would on average need 2,200 kCal per day
67.5% of the food is acquired from arable farming (i.e. cereals)
22.5% of the food is acquired from animal meat
10% of the food is derived from other plant-based or animal products, which are on such a small scale that they don't need extra land. These have therefore been left out of the calculations.

Arable farming (cereals)
One kg of cereals produces 3,100 kCal
One ha produces 1,000 kg per year of which 800 kg can be consumed. The other 200 kg are needed for the next sowing season.
Half of the required kCal per year will be produced as surplus to survive bad years
After a year of arable farming, the land will be fallow
Calculation for the demand of arable farming per person in rural settlement or large settlement
(67.5 % (percentage of diet) x 2,200 kCal (daily need per person) x 365 (number of days per year)) / (800 kg (yearly weight of cereals) x 3,100 kCal (amount of kCal per kilo cereals)) x 1.5 (surplus production) x 2 (to take fallow lands into account) = **0.66 ha of arable farming needed per person**

Pasture and Meadow (for meat)
Every settlement had a herd of approximately 50 animals (cows) which could produce 3,800,000 kCal of meat per year (which they did not have to use)
Every heard needs 16 ha as pasture lands and 10.1 ha meadows.
In periods that lands for arable farming are fallow, these are used as pasture
Calculation for the demand of pasture per rural settlement
(22.5 % (percentage of diet) x 2,200 kCal (daily need per person) x 9.75 (number of persons per settlement) x 365 (number of days per year)) = 1,761,581 kCal
1,761,581 kCal (required production from a herd) / 3,800,000 kCal (maximum production meat of a herd of 50 animals) = 46% of the meat had been used
16 (ha needed for pasture for a herd of 50 cows) **/9.75 – arable farming = approximately 0.97 pasture per person in rural settlement**
10.1 ha meadow needed per settlement / 9.75 = 1.04 ha meadow per person in rural settlement

Table C.2 | *Overview of the assumptions used to calculate land-use demands by military and related settlements in AD 40, AD 70, and AD 140 based on Van Dinter et al. (2014).*

Demand for land
Roman fortress size were derived from the palaeodemographic reconstructions (Appendix A)

An average soldier needs 3,000 kCal per day, a *vicus* inhabitant 2,200
A soldier´s diet had the same ratio as a normal person: i.e. 67.5% cereals, 22.5% meat and 10% other resources that do not need significant land
For *vici* size see palaeodemographic reconstructions (Appendix A)
50% of the cereal was obtained locally, the rest was imported
After AD 70 resources for the Roman army were obtained only south of the border
Arable farming for a soldier (67.5 % (percentage of diet) x 2,700 kCal (daily need per person) x 365 (number of days per year)) / (800 kg (yearly weight of cereals) x 3,100 kCal (amount of kCal per kilo cereals)) x 1.5 (surplus production) x 2 (to take fallow lands into account) = **0.89 ha of arable farming needed per solidier**

Table C.3 | *Overview of the assumptions used to calculate land-use demands of rural-settlement inhabitants, soldiers, and large-settlement inhabitant, based on Van Dinter et al. (2014).*

Land-use type	Needed ha per person	Comments
Rural settlements		
Arable farming	0.70	
Pasture	0.97	
Meadow	1.04	
Soldier		
Arable farming	0.89	
Pasture	0.74	For soldiers we assume that the meat production was more efficient: 22.7 herd (=258.8 ha) was needed per 350 persons. Whereas farms have one heard per farm, produced extra surplus
Meadow	0.65	For soldiers we assume that the meat production was more efficient: 22.7 herd (=229.2 ha) was needed per 350 persons. Whereas farms have one heard per farm, produced extra surplus.
Large settlements		
Arable farming	0.70	
Pasture	0.56	These figures assume that herds for large settlements are as efficient as for military
Meadow	0.49	These figures assume that herds for large settlements are as efficient as for military

Table C.4 | *Demand for land use per modelled scenario.*

		Rural settlements			Military sites and large settlements				Demand for land				
ABR sub-period	#	N of houses per rural settle-ment	N of people per house	N of rural settle-ments	N soldiers (2700 KCal)	N vici people (2030 kCal)	N urban people (2030 kCal)	Total n of people	Arable farming: self-sufficient	Arable farming: surplus	Pasture (self-sufficient and surplus)	Meadow (self-sufficient and surplus)	Unused_ land
Hypothesis 1: Self-sufficiency													
ERP	1	1.5	6.5	1234	8900	14900	0	35832	8091	17978	26521	25631	-78220
MRP	2	3	6.5	1619	5900	5900	9375	52746	21231	15547	43435	44091	-124304
LRP	3	1.5	6.5	664	0	0	0	6474	4354	0	6270	6706	-17330
EMPA	4	3	6.5	306	0	0	0	5967	4013	0	5779	6181	-15973
EMPB	5	3	6.5	856	0	0	1000	17692	11225	672	16723	17784	-46404
EMPC	6	3	6.5	1636	0	0	11500	43402	21454	7734	37294	38711	-105193
EMPD	7	5	6.5	1422	0	0	2600	48815	31079	1748	46207	49155	-128189
ERP	8	3	6.5	1234	8900	14900	0	47863	16182	17978	38174	38094	-110427
MRP	9	6	6.5	1619	5900	5900	9375	84316	42462	15547	74012	76795	-208816
LRP	10	3	6.5	664	0	0	0	12948	8707	0	12541	19241	-40489
EMPA	11	6	6.5	306	0	0	0	11934	8025	0	11559	12362	-31946
EMPB	12	6	6.5	856	0	0	1000	34384	22450	672	32890	35075	-91088
EMPC	13	6	6.5	1636	0	0	11500	75304	42907	7734	68192	71759	-190592
EMPD	14	10	6.5	1422	0	0	2600	95030	62158	1748	90968	97029	-251903
Hypothesis 2: Roman military presence													
ERP	15	3	6.5	1234	8900	14900	0	47863	16182	8989	30740	38094	-94004
MRP	16	6	6.5	1619	5900	5900	9375	84316	42462	7774	67583	71101	-188920
ERP	17	1.5	6.5	1234	8900	14900	0	35832	8091	0	11653	12463	-32207
MRP	18	3	6.5	1619	5900	5900	9375	52746	21231	0	30577	32704	-84512

Hypothesis 3: Dorestad													
EMPC	19	6	6.5	1636	0	0	6500	70304	42907	4371	65412	69296	-181986
EMPC	20	3	6.5	1636	0	0	1500	33402	21454	1009	31733	33786	-87981