

Appendix Table S1 Summary of under-nutrition (UN) and over-nutrition (ON) with pre-weaning outcomes

Study	Over / under nutrition	Maternal treatment	Offspring outcome
Khalaf <i>et al.</i> 1979	Under	Nutrition restricted from GD100 to term; two treatments: either 0.6 or 0.9 requirement	In twin lambs, birth-weight decreased, reduced more with more severe UN. Mortality greater in lambs from more severely UN ewes which also exhibited slower growth rates. No treatment effects on lamb IgG status
Vincent <i>et al.</i> 1985	Under	Nutrition restricted to 0.15 requirement from mating until GD60	Birth-weight reduced and poorer survival for first 48h after birth
Holst <i>et al.</i> 1986	Under	In three experiments, 2 x 2 factorial arrangement of UN between GD45 and GD105 and from GD105 to term. UN estimated as 0.6 and 0.9 of requirement in mid and late gestation	Effects most marked in twins. In all years late UN reduced birth-weight whilst in 2 of 3 years UN in mid gestation increased birth-weight. Mid gestation UN increased lamb mortality
Kleeman <i>et al.</i> 1993	Under	Designed as 2 x 2 factorial experiment but estimation of UN suggests that only UN between	No differences observed in birth-weight and survival

			GD 50 and GD100 (0.7 requirement)	
Bloomfield <i>et al.</i> 2003	Under	Between GD105 and GD115 or GD105 and GD125, ewes were severely undernourished (0.3 MJ/day; control 14 MJ/day)	Birth-weight reduced progressively with length of UN period	
Dwyer <i>et al.</i> 2003	Under	Nutrition restricted to 0.65 of requirement from GD28 to term	Birth-weight reduced. No direct effect on progression of lamb through behavioural repertoire from birth to suckling. UN had adverse effects on maternal behaviour (reduced licking of lamb; increased aggressiveness towards lamb; poorer maternal attachment scores)	
Erhard <i>et al.</i> 2004	Under	Between mating and GD95, ewes fed 0.5 or 1.0 requirement	No difference in birth-weight	
Everett-Hincks <i>et al.</i> 2005	Under / Over	Pasture allowance varied from 800 to 2000 kg DM /ha from GD64 to term. Difficult to estimate intake as proportion of requirement but likely 800 is UN and 2000, ON	Birth-weight reduced in 800 and increased in 2000 kg pasture allowances. No differences in lamb survival. Minor differences in lamb behaviour.	

Wallace <i>et al.</i> 2005	Over	Adult ewes fed to meet requirements or <i>ad libitum</i> (approx. 1.8 requirements throughout gestation)	No difference in birth-weight
Corner <i>et al.</i> 2006a (Morris <i>et al.</i> 2005)	Over	Ewe pasture allowance from GD13 managed to maintain or increase ewe conceptus-free birth-weight by 0.075 or 0.15 kg/day	No effect on birth-weight. No effect on survival. Maternal behaviour score superior on highest plane of nutrition
Burt <i>et al.</i> 2007	Under	Ewes of two contrasting long-term (30 yr) management histories (severe range-land or sedentary) fed 0.5 of requirement between days 28 and 74 of gestation	Birth-weight reduced in sedentary but not range-land ewes
Husted <i>et al.</i> 2007	Under	Nutrition restricted to 0.5 of requirement from GD100	Birth-weight reduced by UN. LWG to day 70 post-natal reduced by UN
Corner <i>et al.</i> 2008 (Corner <i>et al.</i> 2010)	Under	Using 2 x 2 factorial allowance, ewes allocated to two pasture allowances (700 or 1300 kg DM/ha) between GD70 and GD107 or GD107 and term. From maternal live-weight change only ewes maintained on 700 kg DM/ ha UN (estimated 0.6 –	Birth-weight reduced on 700 kg DM/ha throughout allowance. Low-pitched ewe bleats less frequent on UN (poorer maternal care). Differences in lamb bleats

		0.8 of requirement)	
Munoz <i>et al.</i> 2008b	Under/Over	3 x 2 factorial arrangement of nutrition; between mating and day 39 (early), adult ewes fed 0.6, 1.0 or 2.0 requirement and between GD40 and GD90 (mid), 0.8 and 1.4 of requirement	Birth-weight of early UN greater than feeding to meet or exceed requirement. No other birth-weight differences. No differences in mortality. No differences in lamb behaviour due to early treatments. Lambs from ON (1.4 requirement) in mid pregnancy slower to progress through behaviours to suckling: difficult to interpret because comparison is with UN
Tygesen <i>et al.</i> 2008	Under	Ewes mated with either high or low index (<i>L. dorsi</i> cross-sectional area) sire and fed 0.50 of energy intake of controls	Overall birth-weight reduced. Interaction with sire: birth-weight reduction greater with high index sire. Weaning weight of high index sired lambs also reduced
Banchero <i>et al.</i> 2009	Under	From day 130 ewes maintained on native or improved pasture with or without supplementary feed. Difficult to judge degree of UN (no pasture intakes) and there may have been long-term UN	Birth-weight lower and survival poorer on native pasture only diet

		prior to GD130 (maintained on poor quality native pasture)	
Hernandez <i>et al.</i> 2009	Under	Ewes fed approximately 0.5 of requirement from 60 days before to GD30	No differences in birth-weight or ewe and lamb behaviours
Kenyon <i>et al.</i> 2009, 2011; van der Linden <i>et al.</i> 2009, 2010	Over	Using a 2 x 2 factorial design, heavy and light ewes from the same flock were maintained on pasture (1330 v 2304 kg DM/ha) allowances designed to provide maintenance or <i>ad libitum</i> intakes between GD21 and GD140	Lambs born to ad lib ewes were heavier at birth and weaning. However, lamb birth-weight and weight gain of female lambs from ad lib ewes were less and slower than maintenance treatment
Munoz <i>et al.</i> 2009	Under/Over	3 x 2 factorial arrangement of nutrition between mating and GD39 (early), one or two year old ewes fed 0.6, 1.0 and 2.0 requirement and between GD40 and GD90 (mid) 0.8 and 1.4 of requirement	Birth-weight tended to be greater in 2.0 early treatment in 1 year old ewes; birth-weight was lower in 0.6 requirement, early treatment in 2 year old ewes Survival tended to be poorer in lambs from 1 year old UN ewes; no difference in 2 year old ewes Ewes (1 year old) undernourished in early pregnancy showed reduced maternal care. In mid-pregnancy

			UN ewes exhibited better maternal care and their lambs suckled faster than ON ewes
Swanson <i>et al.</i> 2008; Neville <i>et al.</i> 2010; Hammer <i>et al.</i> (expt 1;2011)	Under/Over	Between GD50 and term, ewes were fed 0.6, 1.0 or 1.4 of requirement	Birth-weight was reduced in both UN and ON treatments. No difference in weight gain to weaning. Mortality greater in ON treatment. Lamb plasma IgG greater in UN treatment and reduced in ON treatment
Meyer <i>et al.</i> 2010; Hammer <i>et al.</i> expt 2, 2011	Under/Over	Between GD40 and term, ewes were fed 0.6, 1.0 or 1.4 of requirement	Birth-weight and early LWG (to day 19) tended to be reduced in UN treatment. No difference in mortality. Lamb IgG was greatest in UN and lowest in ON treatment
Rooke <i>et al.</i> 2010	Under	Using a 2 x 2 factorial design, ewes of two contrasting breeds were fed 0.75 or 1.0 requirement from GD1 to GD90	While birth-weight of a breed selected for rapid lean tissue growth was reduced by UN, there was no effect on a breed selected to withstand a harsh environment. Survival was poorer in lambs from UN ewes. UN ewes expressed poorer levels of maternal care. Lambs from UN ewes were slower to progress

			through behaviour to suckling
Ferguson <i>et al.</i> 2011; Oldham <i>et al.</i> 2011; Thompson <i>et al.</i> 2011	Under/Over	Multisite / multiyear expt (2 yr/ 2 sites). 2 x 5 factorial design. Ewes fed to lose / maintain weight/condition score between GD0 and GD100 and then offered 5 pasture allowances (800, 1100, 1400, 2000 and >3000 kg DM /ha) from GD100 until weaning. From weights, GD0-100 UN estimated 0.7 requirement. Post GD100 all treatments appear greater than requirement with possible exception of 800 kg DM/ha.	Early (day 0 to 100) UN: birth-weight reduced in 2 of 4 (site/year) combinations. No effect on lamb survival or LWG to weaning. Day 100 to term: In 3/4 site/year occasions, birth-weight reduced at 800 kg DM/ha. No differences between higher allowances. Same effect for survival and weaning weight
Kenyon <i>et al.</i> 2011	Under/Over	Using a 3 x 2 factorial design ewes were offered pasture to achieve intakes equivalent to 0.6, 1.0 and 1.5 requirement between GD30 and GD50 and to meet 1.0 or 1.5 requirement between GD50 and term	No effect of early (days 30 to 50) nutrition on birth-weight or LWG to weaning; Lambs born to ON ewes (d 50 to term) were lighter at birth
Wallace <i>et al.</i> 2011	Under/Over	Ewes (8 month old) consumed 0.75, 1.0 or ~2.2	Both UN and ON reduced birth-weight; no difference

requirement from GD7 to term

in live-weight at weaning

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Appendix Table S2 Summary of studies where specific nutrients in ewe diet were changed and resulting lamb pre-weaning outcomes

Study	Nutrient	Maternal treatment	Offspring outcome
Quirk & Norton, 1987	Co	Ewes grazing low Co (<0.1 mg/kg DM) supplemented with 0.03 or 0.06 mg Co /day throughout gestation	Birth-weight and LWG to weaning increased by supplementation; no difference between levels of Co
Fisher & MacPherson 1991	Co	Ewes fed Co deficient (0.06 mg/kg DM) or supplemented (0.1 mg Co/day). Supplemented diets fed throughout; from GD0 to GD74;or from GD74 to term	Mortality reduced by supplementation; no effect on birth-weight; lamb behavioural progress faster with supplementation throughout; supplementation day 0- 74 intermediate
Kott <i>et al.</i> 1998	Vit E	Supplementary vitamin E fed from GD120; increased intake from 20 to 158 mg/ kg diet DM	Season dependant response. In first half of lambing season supplementation reduced mortality and increased growth rate to weaning
Encinias <i>et al.</i> 2004	FA	Ewes fed diet in which safflower seed replaced maize from GD100	No difference in birth or weaning weight. Survival improved with safflower. No evidence for improved thermoregulation with safflower seed
Boland <i>et al.</i> 2005b, 2006	I	Expt 1 Ewes fed supplements from GD100 containing supplementary minerals; minerals with	Expt 1 no effect on birth-weight or colostrum intake; I only or all minerals depress lamb IgG

		iodine excluded or iodine only (40 mg/day)	absorption and plasma vitamin E concentration
		Expt 2 Ewes fed from GD100 with 9, 18 and 27 mg I/day	Expt 2 Progressive depression in lamb plasma IgG and vitamin E concentration as amount of I fed increased
Capper <i>et al.</i> 2005, 2006	FA / Vit E	Using a 2 x 2 factorial design ewes were fed from GD100, low (50 mg/kg) or high (500 mg/kg) vitamin E and saturated (Megalac) or unsaturated (fish oil) fatty acid (60 g/kg) containing diets	Vitamin E: increased birth-weight; no effect on maternal care or lamb behaviours Fatty acids: no effect on birth-weight; lambs born to fish oil fed ewes suckled more quickly
Chen <i>et al.</i> 2007	FA	Using a 2 x 3 factorial design ewes were fed from GD107, diets containing 20, 40 or 80 g/kg, saturated or polyunsaturated fatty acid (linseed) supplements	No birth-weight differences. Rectal temperature after cold exposure lower on 80 g/kg diet (no fatty acid effect) and ability to oxidize fatty acids reduced
Mitchell <i>et al.</i> 2007	Co	Ewes were supplemented or not supplemented with a Co bolus 24 days before mating	No birth-weight differences. Supplemented lambs slower to progress through behavioural milestones
Rose <i>et al.</i> 2007	I	Ewes were supplemented with increasing amounts of I from GD102; 6 levels from 0 to 20 mg/kg diet DM	Birth-weight increased with increasing I supplementation; no difference in weaning weights. Plasma IgG at 24 h o age decreased

			linearly with I supplementation
Boland <i>et al.</i> 2008	I	Ewes were fed no supplementary I or 27 mg I/day from GD126 or 27 mg /day from GD140	I fed for 7 days reduced birth-weight; fed for 21 d - no reduction. Lamb plasma IgG at 24 h of age reduced more severely by feeding I for 21 d rather than 7 d. Lamb plasma vitamin E reduced by I supplement at 72 h of age
Munoz et al 2008a	Se	Ewes fed supplement (or not) of 0.5 mg Se / day from mating to GD90	No difference in birth-weight but mortality lower in Se-supplemented treatment. Se-supplemented lambs grew faster to weaning. Plasma IgG higher in Se-supplemented lambs and these lambs showed more rapid behavioural progress
Dafoe <i>et al.</i> 2008	FA / Vit E	Using a 2 x 2 factorial design, from GD100 to GD135 ewes were fed either barley or safflower seed (PUFA) based diets with or without 350 mg/kg vitamin E	No differences in birth-weight, weaning weight or mortality. Thermoregulation was poorer in safflower seed diet with no vitamin E supplement
Pickard <i>et al.</i> 2008	FA	From GD80 onwards, ewes were fed or not fed a supplement containing 12 g DHA / day between GD84 and GD105, GD84 and GD126, GD84 and	No difference in birth-weight or live weight gain. All supplemented lambs were quicker to stand than un-supplemented lambs

		term	
Annett <i>et al.</i> 2008	FA	Ewes were fed barley-based diet containing or not containing fish oil (74 g/kg) from GD105	Feeding fish oil had no effect on birth or weaning weights but reduced lamb plasma IgG at 24 h of age
Annett <i>et al.</i> 2009	FA	Ewes were fed 20 or 40 g/day of either herring or salmon oil from GD105	Feeding fish oil reduced ewe colostrum IgG output and lamb IgG concentration at 24 h of age No effect on lamb birth or weaning weight. Lamb survival improved by fish oil; quadratic response with benefits greatest at 20 g/day
Rooke <i>et al.</i> 2009	Vit E	Ewes were fed increasing amounts (from 50 to 250 mg/day from GD98	No effect of vitamin E on birth or weaning weights, or upon behavioural progress of lambs to sucking
Swanson <i>et al.</i> 2008; Neville <i>et al.</i> 2010; Hammer <i>et al.</i> expt 1; 2011	Se	From mating, ewes were offered adequate (10 µg /kg live-weight) or high Se (82 µg/kg live-weight)	No effect on birth or weaning weights; plasma IgG at 24 h of age lower in high Se; no effect on mortality
Kerslake <i>et al.</i> 2010	I	Ewes were injected or not injected with 0.39 g iodine, 25 days before mating	No effect on lamb birth-weight, rectal temperature, plasma IgG or thyroid hormones.

			Basal heat production greater in I-treated lambs but on effect on maximal heat production
Meyer <i>et al.</i> 2010; Hammer <i>et al.</i> expt 2, 2011	Se	From mating, ewes were offered adequate (4 µg /kg live-weight) or high Se (65 µg/kg live-weight)	No effect on birth-weight; no effect on mortality of plasma IgG at 24 h of age
Keithly <i>et al.</i> 2011	FA	From GD117, ewes were fed or not fed 12 g DHA / day	No effect on birth-weight but DHA-treatment lighter at 38 days of age. No difference in thermoregulation

Table S3 Summary of studies where a behavioural or physiological stress was applied to the ewe and resulting lamb pre-weaning outcomes were measured.

Study	Stressor type	Maternal treatment	Offspring outcome
Stott & Slee 1985	Environment / Husbandry	Ewes either maintained in warm (26 °C) or control environment (6°C) or cold stressed (shorn and exposed to -20 °C for 2h daily for 7 d) from 14 days before lambing	Lambs from cold-stressed ewes had smaller decrease in rectal temperature at 12 h old than control or warm treatments and greater increase in metabolic rate in response to adrenaline challenge at 36 h old
Moss <i>et al.</i> 2001	Artificial	Ewes given a single (1 x ;GD104) or four (4 x ;GD104, GD111, GD118, GD125) injections with betamethasone	Survival of 4x treated lambs was lesser than control or 1x lambs. Birth and 3 month of age weight lower in 4x lambs; 1x birth-weight intermediate
Kenyon <i>et al.</i> 2004	Husbandry / shearing	Twin-bearing ewes were shorn at GD70	Lamb birth-weight increased by shearing. Weaning weights but not rate of weight gain to weaning increased
Roussel <i>et al.</i> 2004	Social	Ewes isolated for 1h in presence of absence of dog	Pre-natally stressed lambs had greater birth-

		weekly for last 5 weeks of pregnancy (total of 10 occasions)	weights but no difference at 8 month of age. Cortisol response to isolation at 25 d old not different.
Kenyon <i>et al.</i> 2005	Husbandry / shearing	Twin bearing ewes shorn or not shorn at day 70; unshorn ewes not treated or treated with thyroxine (GD55, GD70, GD115) with or without thyroidectomy (GD55)	Lamb birth-weight increased by shearing; no effect of thyroid treatments. No treatment effect on weaning weights
Roghair <i>et al.</i> 2005	Artificial	Ewes infused with betamethasone continuously for 48 h at GD27	Birth-weight greater in treated lambs (but litter size smaller)
Corner <i>et al.</i> 2006b	Husbandry / shearing	Ewes were fasted for 24 h and handled with dogs on GD79 and GD80 and then not shorn (yarded) or shorn (shorn)	Shorn treatment increased lamb birth-weight; yarded no effect. No treatment effect on maternal behaviour but fewer lambs from shorn treatment did not suckle successfully
De Blasio <i>et al.</i> 2007	Artificial	Ewes infused with betamethasone or cortisol continuously for 48 h at GD27	Birth-weight tended to be lower in betamethasone treatment; cortisol no effect

Corner <i>et al.</i> 2007	Husbandry / shearing	Ewes shorn or not shorn on GD79	Birth-weight greater in shorn treatment; no differences in cortisol response to stress (castration) between treatments
Roussel-Hachette <i>et al.</i> 2008	Social	Ewes were either isolated in presence or absence of dog or transported in isolation for 1 h; treatments applied on 10 occasions over last 5 weeks of pregnancy	No effect of treatments on birth-weight but lambs from isolated treatment heavier at 3 months than control or transport treatments
Keady & Hanrahan. 2009	Husbandry / shearing	Ewes shorn or not shorn on GD63	Birth-weight increased by shearing. Weaning weights and weight gain to weaning not increased by shearing. No difference in mortality
Miller <i>et al.</i> 2009	Artificial	Ewes injected with dexamethasone (low or high dose) on either GD130 or GD141 of pregnancy	No effect of treatment on birth-weight or survival. Lambs born to dexamethasone treated ewes latency to bleat longer; no other differences in lamb behaviour
Banchero <i>et al.</i> 2010	Husbandry / shearing	Treatments were shearing of the ewe at GD70 or GD120 of gestation	Birth-weight of twin lambs greater on day 70 treatment than day 100 than unshorn treatments;

			singletons not significant. More lambs from both shorn treatments suckled successfully than controls irrespective of litter size
Corner <i>et al.</i> 2010b	Husbandry / shearing	Ewe treatments applied: (a) isolation for 1h on 2 occasions (GD75 ,GD78); (b) isolation for 1 h on 10 occasions (between GD75 and GD105; (c) injection of cortisol on 10 occasions between GD75 and GD105; (d) sham-shorn on 10 occasions between GD75 and GD105; (e) shorn on GD76	Birth-weight increased by shorn and decreased by cortisol treatments. No differences from control in live-weight at 63 days old
Cal-Pereyra <i>et al.</i> 2011	Husbandry / shearing	Ewes shorn or not shorn on GD110	No birth-weight increase in response to shearing
Hild <i>et al.</i> 2011	Husbandry	Ewes daily subjected to gentle or aversive handling for last 32 days of pregnancy	Aversive treatment resulted in tendency for greater weight at 24h of age; no differences in lamb neonatal behaviours; ewes aversively handled groomed lambs for longer
Sphor <i>et al.</i> 2011	Husbandry /	Ewes shorn or not shorn on GD53	Single-bearing ewes only; increase in birth-weight

shearing

and weaning weight and rate of gain to weaning
in response to shearing

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