Programme Area: Bioenergy

Project: ELUM

Title: Updated Meta-analysis Database & Report for 2012/2013

Abstract:

This report (deliverable D1.6) is an extension from December 2011 out to December 2013 of deliverable D1.5 (ELUM literature review). The aim of the literature review was to assess the state of the current literature with respect to the effects of land-use change (LUC) to bioenergy crops on greenhouse gas emissions and soil processes. A systematic reviewing and meta-analytical approach has been used, specifically focussing on total soil carbon, soil organic carbon and greenhouse gas emissions. This work identified where published data for UK-relevant LUC is adequate, and more importantly, where there are significant gaps or weaknesses in the literature. The findings from this updated analysis are generally in agreement with the original ELUM literature review, deliverable D1.5.

For further more detailed information please see the published paper at the following URL.

http://onlinelibrary.wiley.com/doi/10.1111/gcbb.12347/full

Context:

The ELUM project has studied the impact of bioenergy crop land-use changes on soil carbon stocks and greenhouse gas emissions. It developed a model to quantitatively assess changes in levels of soil carbon, combined with the greenhouse gas flux which results from the conversion of land to bioenergy in the UK. The categorisation and mapping of these data using geographical information systems allows recommendations to be made on the most sustainable land use transition from a soil carbon and GHG perspective.

Some information and/or data points will have been superseded by later peer review, please refer to updated papers published via www.elum.ac.uk

ETI Project code: BI1001

Ecosystem Land-Use Modelling & Soil C Flux Trial (ELUM)

Management & Deliverable Reference: PM07.1.6

Updated Meta-analysis Database & Report for 2012/2013

REPORT

v1.1

23/06/2014

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EXECUTIVE SUMMARY

This short report provides an update of the previous deliverable, D1.5 (ETI report reference - BI1001_ELUM_PM06.1.5_Meta-Analysis v2.0). The objectives of the original deliverable were to assess the state of the current literature on the impacts of land-use change (LUC) to bioenergy crops for GHG and soil processes. We aimed to quantify the scale of these effects, using a systematic reviewing and meta-analytical approach where possible, specifically focusing on Total Soil Carbon (TSC), Soil Organic Carbon (SOC) and Greenhouse Gas emissions (GHG). Here, we include new literature published up until Dec 2013. Accompanying this report are an updated meta-analysis database which reviews all of the TSC, SOC and GHG data evaluated from the selected literature sources arising from the systematic review, using terms as defined previously. The meta-analysis used the parameters described in earlier deliverables, D1.3 and D1.2 respectively, and an improved modified methodology which was implemented as a result of additional funding.

This work identified where published data for UK-relevant LUC is adequate, and more importantly, where there are significant gaps or weaknesses in the literature.

The findings from this updated analysis are generally in agreement with deliverable D1.5, where it was found that transitions from arable to second generation bioenergy crops (SRC and perennial grasses – meaning Miscanthus and similar types) generally results in reduced GHG emissions and increased carbon stored in the soil. The conversion from grassland systems to second generation (2G) bioenergy crops was generally less certain when considering GHG emission and soil properties. Conversions to first generation bioenergy crops (1G) from grassland or forest resulted in increased GHG emissions and decreases in soil carbon. This analysis also found there was a significant decrease in soil organic carbon as a result of a transition from forest to SRC. In general, these findings are in agreement with those in the extensive literature review of D1.2 and confirm earlier modelled results from some members of the consortium (Hillier *et al.*, 2009).

A limitation in this analysis is the availability of empirical data which documents the effects of land-use conversions to bioenergy crops. Field-based measurements are in short supply for soil properties and GHG emissions. The only data which conform to strict meta-analytical requirements are those from empirical measurements that produce an error term and pre-conversion and post-conversion information. Thus our meta-analysis had strict criteria for inclusion. Where this level of information was unavailable in adequate numbers of replicated studies, data were not used in the current meta-analysis and no boot-strapping was applied. Instead a summary figure was generated by creating a mean from the available data and a descriptive narrative provided such as may be found in a standard literature review.

The meta-analysis conducted quantifies the effects of LUC to bioenergy, but results need to be interpreted with caution, primarily due to limited primary data sources. The deliverable does confirm the essential importance of collecting further long-term empirical data-sets on the impacts of land-use transitions on soil-based processes – these remain inadequate and are addressed in the short-term by ELUM, but both more studies and longer data-sets are required than those provided by the limited time-frame of this project.

As with the previous deliverable, all updated data in the database are available to WP4 for model improvement, parameterization and testing and the database of references used and data analysed will be provided to ETI.

The deliverable and acceptance criteria for this report were as follows:

Deliverable D1.6:	Updated meta-analysis database & report for 2012/2013
Acceptance Criteria:	WP1 meta-analysis database to be updated to reflect systematic literature search hits for publications emerging during 2012 and 2013 (as per D1.5). A short (6-10 page) report will provide additional context and update based on the findings.

References to other ELUM Reports

The reader's attention is drawn to the following additional ELUM reports which are referred to in this report:

- BI1001_PM08.1.2_LUC Transitions v1.1
- BI1001_PM04.1.3 Meta-Analysis Database Report v1.1_Revised
- BI1001_ELUM_PM06.1.5_Meta-Analysis v2.0

CONTENTS

1. AIMS

The over-arching aim of this deliverable is to determine the effects of land-use change to bioenergy cropping systems on soil organic carbon (SOC), total soil carbon (TSC) and greenhouse gas emissions (GHG). This will be achieved using existing databases from deliverable D1.5 and will additionally include literature from an updated search to the end of 2013.

2. METHODS

An extended methodology including details of how the methodology differed in this deliverable to previous deliverables can be found in appendix I. A full reference list of all papers included in analysis can be found in appendix V.

2.1 Literature Search

The update to the literature search was performed using Web of Science in two stages: the first was performed in the summer of 2013 to collect all papers from 2012 to mid-2013[1], and the second was completed in January 2014 to capture the rest of the 2013 papers. These papers were all imported to an EndNote Library for processing. Figure 2.1 shows the number of unique paper hits for the two respective searches after duplicates were removed.

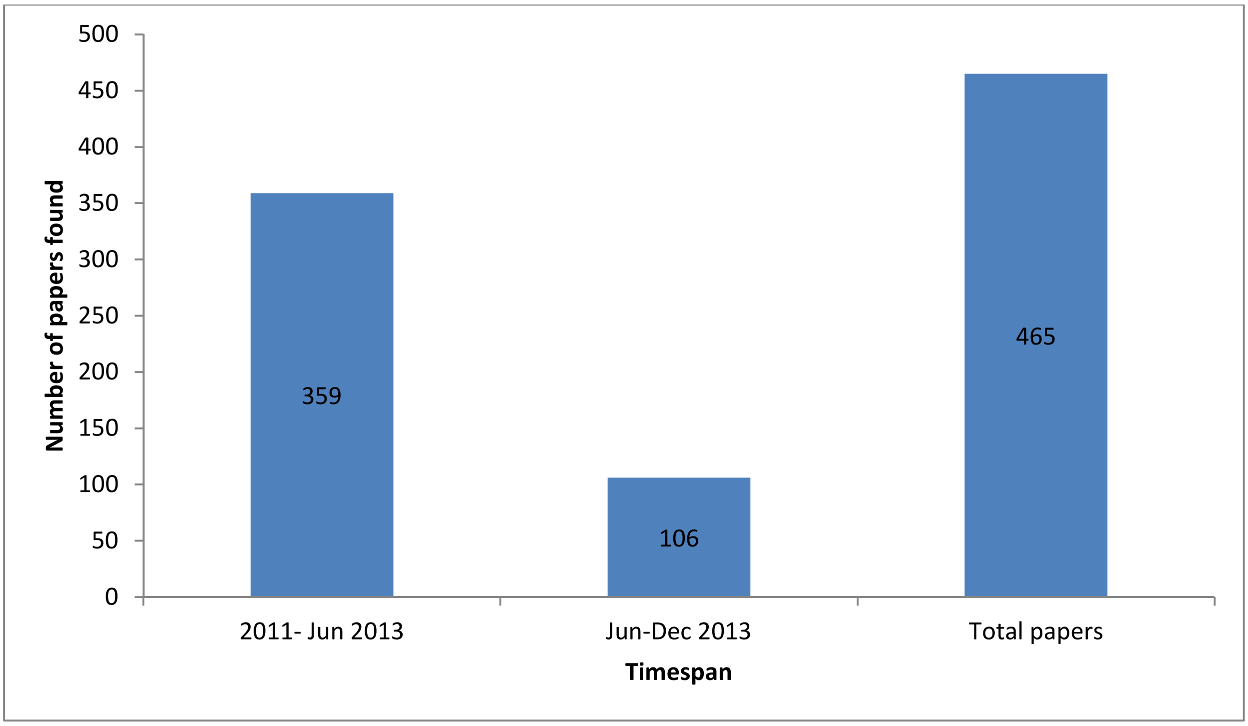

Figure 2.1: Number of papers found from searches conducted on 18th June 2013 for the timespan 2011-June 2013 and for the search conducted on 29th January 2014 for Jun-Dec 2013. The total number of papers is also shown.

[1] * Search conducted covering 2011-mid-2013 to ensure all data was collected and none missed – all duplicates were deleted

The papers were processed by first screening and assigning a 'yes', 'no' or 'maybe' rating, using previous criteria (see D1.5), then all papers considered 'yes' or 'maybe' were considered in more detail. Of these papers, there were 4 possible outcomes (Figure 2.2):

1. No usable data within the paper
2. Data was useful and extracted
3. Data had already been extracted for D1.5
4. Authors were contacted for additional information

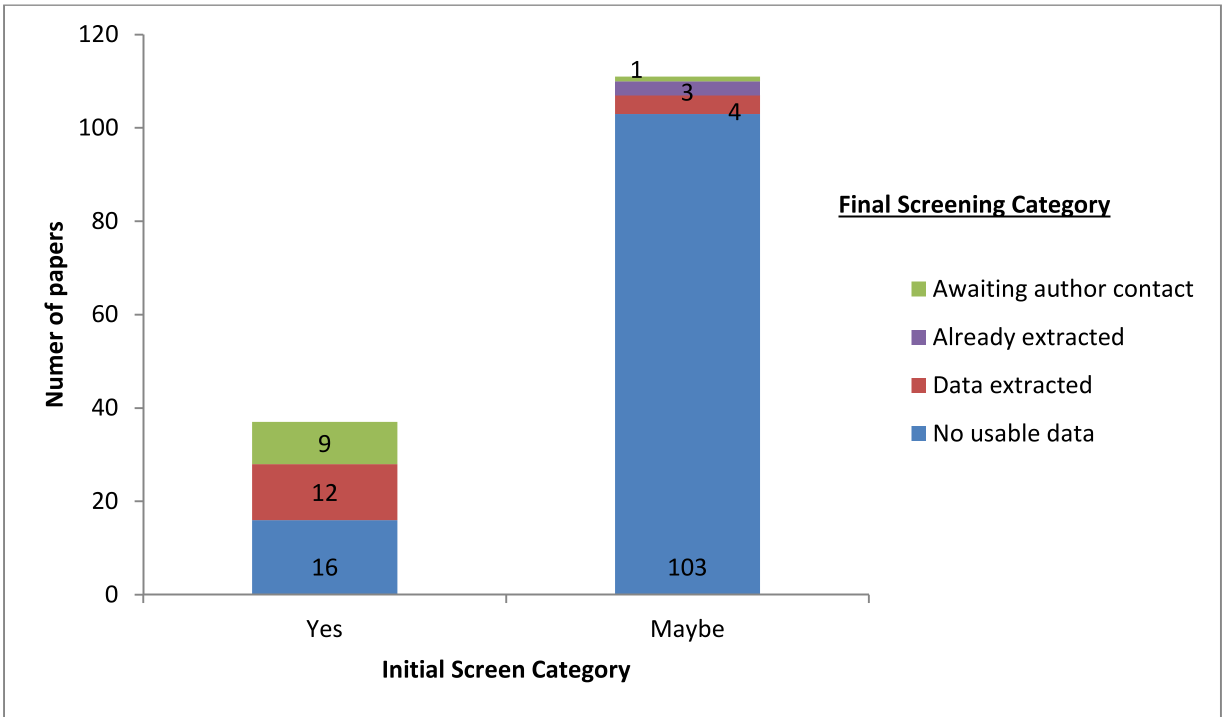

Figure 2.2: Outcomes of second level processing of all papers from systematic search.

Authors were contacted when there was additional information or confirmation required, such as error terms or pre-transition values. Many of the authors contacted responded positively to the enquiry and it was noted that papers published more recently (in 2012/2013) had a higher likelihood of response from the corresponding author.

It is extremely important when undertaking a data-mining exercise that the scope of interest is strictly defined; the same criteria has been used for the previous deliverables (See D1.5) but was not stated as explicitly previously:

- the location (to be relevant to the UK context - therefore temperate and not tropical)
- the species concerned (inclusive of 1G and 2G bioenergy crops, but only those relevant to the temperate land-use defined above)
- be for a conversion to bioenergy, stating a pre-existing land-use value and a post-conversion land-use value (papers were also eligible if they were documenting a land conversion not for use as bioenergy, but were using the same land management practices as would be used for bioenergy cultivation)

- the mention of the metrics which we used in the meta-analysis
    - Soil Organic Carbon in t C ha^{-1} y^{-1} (or convertible figure)
    - Total Soil Carbon in t C ha^{-1} y^{-1} (or convertible figure)
    - GHG emissions for crop life cycle, partitioned into CO_2, N_2O, CH_4 or 'all' in t CO_2-eq ha^{-1} y^{-1} (or convertible figure)

2.2 Meta-Analytical Methods

In order to perform a meta-analysis three key values are needed, a mean ($\bar{x}$), a standard deviation (SD) and a sample size (n). And in order to assess the relative effect of a change from one land use to another, a starting value is required, enabling a pre- land-use change estimate of soil properties and GHG balance and a post-conversion estimate to be used. Where either error terms or a pre-land use value were unavailable, authors were contacted for additional information. Where these data remained unavailable, strict meta-analysis techniques could not be used and thus, much useful information was lost from the meta-analysis, but is still relevant to the narrative review being developed (draft paper in publication).

An intuitive effect size, more commonly used in ecology, is the Log Response Ratio (ln(R)) as measures are on a physical scale and possess a natural zero point. The other advantage of using ln(R) is the ability to transform the effect size into a percentage change, therefore bringing an ease of interpretation to the reader, which represents an improvement to D1.5 where we used Hedges *G* effect size. The calculation of the effect size and transformation into a percentage can be seen in equations 2.1 and 2.2.

$$lnR = ln(R) = ln\left(\frac{\bar{X}_1}{\bar{X}_2}\right) = ln(\bar{X}_1) - ln(\bar{X}_2) \tag{2.1}$$

$$\%\, change = (exp(lnR) - 1)x\ 100 \tag{2.2}$$

SOC data were extracted from 6 additional papers and for TSC data were extracted from 4 additional papers; each observation was entered as a 'study' and this notation will be used from this point on in text and figures. Both SOC and TSC had sufficient data to conduct a meta-analysis on certain transitions. The meta-analysis was conducted in R, since the software package used previously in deliverable report D1.5 (CMA) was unable to compute ln(R). A test for publication bias was conducted for each of the analyses by plotting a funnel plot of the log ratio of the means against the standard error. The presence of symmetry in all the plots indicated little to no publication bias (Appendix II).

There were insufficient data to conduct a meta-analysis on the effect of land-use change to bioenergy on GHG emissions. Therefore, with the data that were extracted, an arithmetic mean, SD and sample size were taken and presented in a standard histogram. There were sufficient data to assess the effects on CO_2 emissions and N_2O emissions, but there were insufficient data for some transitions and for the effect on CH_4 emissions. A total of 21 papers contributed to this part of the analysis. Figure 2.3 illustrates the total number of studies which were included for each of the measures of interest, a further breakdown can be found in Appendix III.

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Some papers which were found to be suitable for use in the previous analysis (D1.5) were deemed no longer suitable for this analysis due to the revised methodology as discussed above. Whilst it may be desirable to compare the outputs from the previous analysis (D1.5) this would not be possible due to the improved methodology used here in this analysis. The data contained in this report includes both the original (D1.5) and new data captured from the updated search.

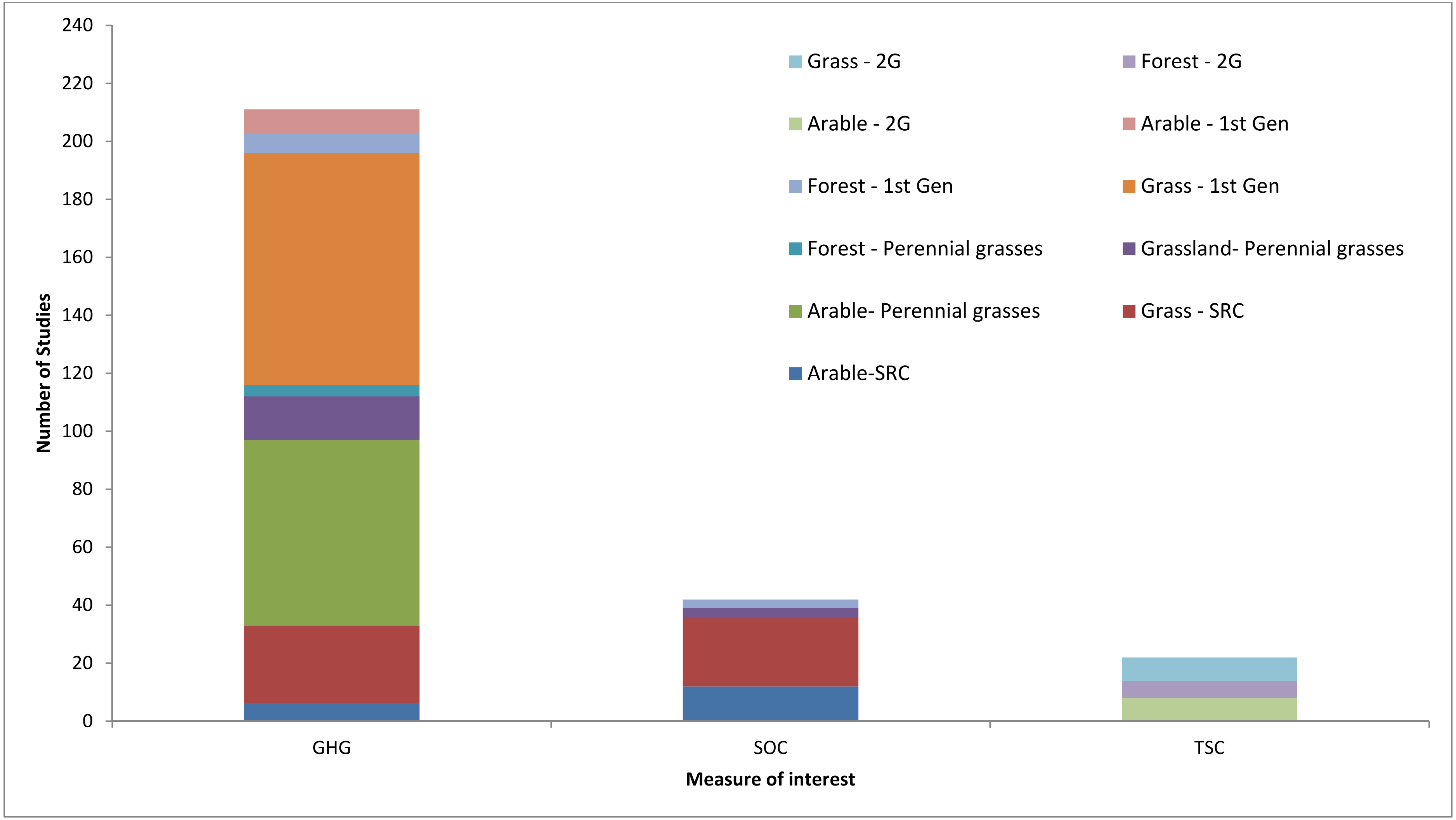

Figure 2.3: Total number of studies which contributed to each analysis for all combined greenhouse gases (GHG), soil organic carbon (SOC) and total soil carbon (TSC).

3. RESULTS

The most striking result found from conducting this work is that there is a clear lack of empirical studies looking at conversions to bioenergy cropping systems, and where data do exist, they were often unsuitable for utilisation in a strict meta-analysis approach. Table 3.1 illustrates where there was sufficient data to carry out a robust meta-analysis for each of the specified metrics. Where a strict meta-analysis could not be conducted due to limited data points, a traditional assessment using means and variance was undertaken and although this should be interpreted with caution, there is no reason to believe that such an approach is in error, but it perhaps has less certainty than the strict meta-analysis outcome.

Due to the scarcity of the data, it was not possible to partition transitions by age after transition: the average time since transition was 6.5 years (X_{max}=16, X_{min}=1) and 6.7 years (X_{max}=15, X_{min}=2) for SOC and TSC respectively. It was also not possible to partition by sampling depth, the majority of studies looking at SOC and TSC at the 0-30cm profile, though further depths were covered (ranges of 0-150 cm and 0-50 cm for SOC and TSC respectively). Therefore conclusions drawn from this meta-analysis can be considered appropriate for transitions up to 15 years after transition to bioenergy cropping.

Table 3.1: Summary of where there was sufficient data to conduct a meta-analysis for land-use change to bioenergy cropping systems. Where this was not possible a summary figure was constructed.

	Soil Organic Carbon	Total Soil Carbon	GHG Emissions
Arable → SRC	✓	✓ *	Summary figure
Grass → SRC	✗	✓ *	Summary figure
Forest → SRC	✓	✓ *	✗
Arable→ Perennial Grasses	✓	✓ *	Summary figure
Grass → Perennial Grasses	✓	✓ *	Summary figure
Forest → Perennial Grasses	✗	✓ *	✗
Grass → 1st Gen Crops	✗	✗	Summary figure
Forest → 1st Gen Crops	✗	✗	Summary figure
Arable → SRF	✗	✗	✗
Grass → SRF	✗	✗	✗
Forest → SRF	✗	✗	✗
✓ *: Analyses were combined to 'transition to 2G' due to lack of data for individual species			

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3.1. Soil Organic Carbon

Four transitions were assessed for SOC; the summary of the meta-analysis output can be seen in Table 3.2, as well as percentage change summary plots in Figure 3.1.

Table 3.2: Meta-analysis outputs for land use transitions to bioenergy on Soil Organic Carbon (SOC). Negative % change denotes a loss in SOC. *n*=number of studies.

	ln(R)		% change		*p* value	*n*
	Effect Size	SE	Percentage Change	SE		
Arable – Perennial Grasses	0.06	0.05	6.4	11.1	0.2458	24
Arable – SRC	0.10	0.05	10.4	10.2	0.0460*	12
Forest – SRC	-0.33	0.15	-28.2	34.6	0.0289*	3
Grass – Perennial Grasses	-0.01	0.09	-1.1	18.5	0.8953	3

There were sufficient data to conduct a meta-analysis from arable to perennial grasses and from arable to SRC, both showing that a transition to 2G cropping resulted in an increase in SOC. Arable to perennial grasses showed a +6.4% (±11.1% SD) increase in SOC, though this was not statistically significant. Arable to SRC on the other hand showed a statistically significant increase in SOC of +10.4% (±10.2%). As for grassland transitions, there was only sufficient data for a transition to perennial grasses; this showed a small decrease in SOC of -1.1% (±18.5%), though this was not significant. A transition from forest ecosystems to SRC showed a large significant decline in SOC on -28.2% (±34.6%) which was significant at the 5% level of probability.

3.2. Total Soil Carbon

Three transitions were assessed for TSC; the summary of the meta-analysis output can be seen in Table 3.3, as well as percentage change summary plots in Figure 3.2.

Due to the lack of data on transitions to individual bioenergy cropping systems (i.e. perennial grasses and SRC), it was decided that to increase the power of the meta-analysis these would be combined to have 'transition to second generation' (2G).

Table 3.3: Meta-analysis outputs for land-use transitions to bioenergy on Total Soil Carbon (TSC). Negative % change denotes a loss in TSC. *n*=number of studies, number in bracket are the number of studies from each cropping type – SRC, 'Per' for perennial grasses and '2G' where these are already combined within the study.

	ln(R)		% change		*p* value	*n* *(SRC, Per, 2G)*
	Effect Size	SE	Percentage Change	SE		
Arable – 2nd Gen	0.02	0.07	2.5	15.0	0.7304	8 (6, 1, 1)
Forest – 2nd Gen	-0.04	0.11	-3.9	25.0	0.7265	7 (4, 0, 3)
Grassland – 2nd Gen	0.03	0.07	3.2	14.5	0.6533	8 (1, 0, 7)

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Transitions from both arable and grassland showed a small increase in TSC as a result of the transition, +2.5% (±15.0%) and +3.2% (±14.5%) respectively. Land-use change from forest to 2G cropping showed a loss of TSC of -3.9% (±25.0%), however this and both previous transitions were not significant results.

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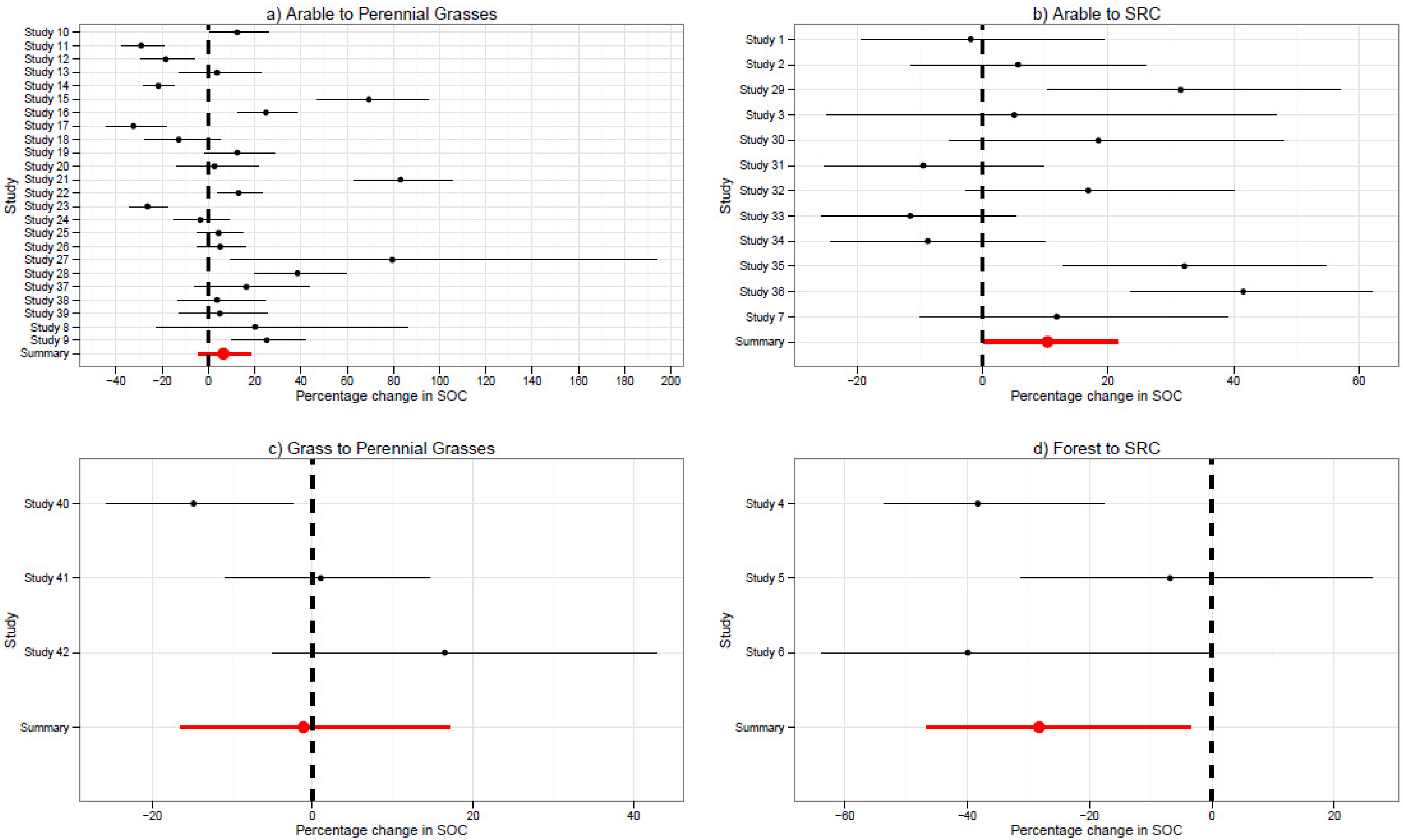

Figure 3.1: Percentage change of SOC as a result of land-use change to bioenergy crops. Individual study data are shown in black and summary effect sizes are shown in red with the mean and 95% confidence intervals. Results are significant where the effect sizes and confidence intervals do not cross the zero line.

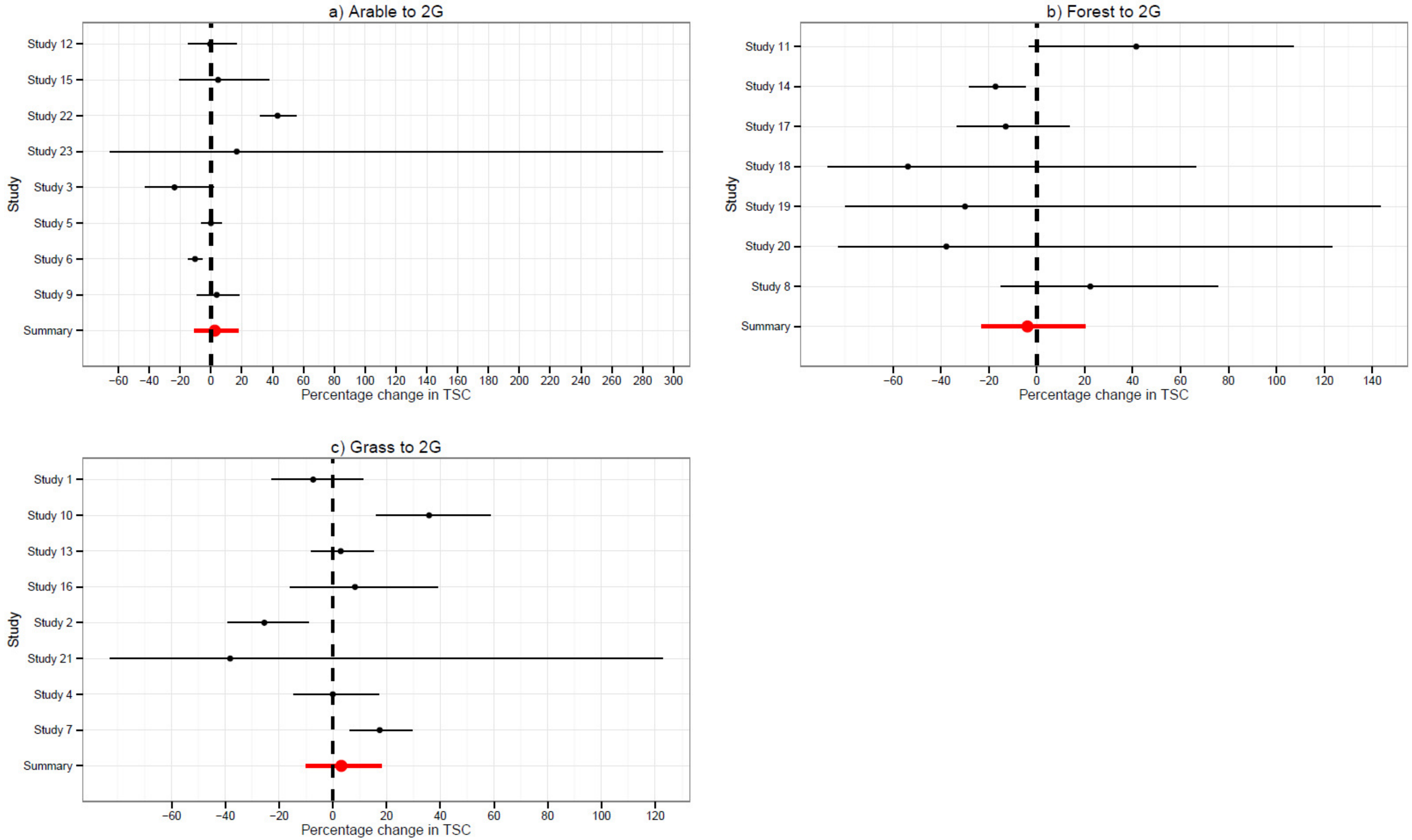

Figure 3.2: Percentage change of TSC as a result of land-use change to bioenergy crops. Individual study data are shown in black and summary effect sizes are shown in red with the mean and 95% confidence intervals. Results are significant where the effect sizes and confidence intervals do not cross the zero line.

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3.3. Greenhouse Gas Emissions

There were insufficient GHG emissions data to perform a meta-analysis and in this case, a summary figure was developed to show the general trends of GHG changes as a result of land-use change to bioenergy crops (Figs 3.3 & 3.4).

The effect of land-use change to bioenergy on CO_2 emissions can be seen in Figure 3.3, showing that transitions from arable to 2G crops results in an increased emission of -2.1 and -2.2 t CO_2-eq ha^{-1} y^{-1} for SRC and perennial grasses respectively. The transition from arable to 1G cropping shows very little change as this is only likely to be due to a small change in management regime, rather than crop species planted. The grassland to bioenergy transitions show very little change in CO_2 emissions, with little to no change for SRC (0.3 t CO_2-eq ha^{-1} y^{-1}), a slight decreased emission from grassland to perennial crops (-0.8 t CO_2-eq ha^{-1} y^{-1}) and a slight emission from grass to 1G (2.0 t CO_2-eq ha^{-1} y^{-1}). Forest to 1G cropping shows the most pronounced emission event at 26.5 t CO_2-eq ha^{-1} y^{-1}.

Figure 3.4 shows the effect of land-use change to bioenergy on N_2O emissions; where there was insufficient data this is indicated on the graph. Similarly to CO_2 emissions, the effect of conversion from arable to 2G bioenergy cropping shows a reduced emission of -0.2 and -0.4 t CO_2-eq ha^{-1} y^{-1} for SRC and perennial grasses respectively. Similarly to CO_2 emissions, there was little effect on the conversion from arable to 1G cropping of -0.1 t CO_2-eq ha^{-1} y^{-1} which again may be due to a change in fertilization regime. There was insufficient data for grassland to 2G bioenergy cropping, but a transition to 1G showed an emission of 0.5 t CO_2-eq ha^{-1} y^{-1}.

There was insufficient data to assess the effects of land-use change to bioenergy on methane emissions, though current work within the consortium indicates that methane only plays a minor role in the overall GHG balance during LUC to bioenergy cropping systems.

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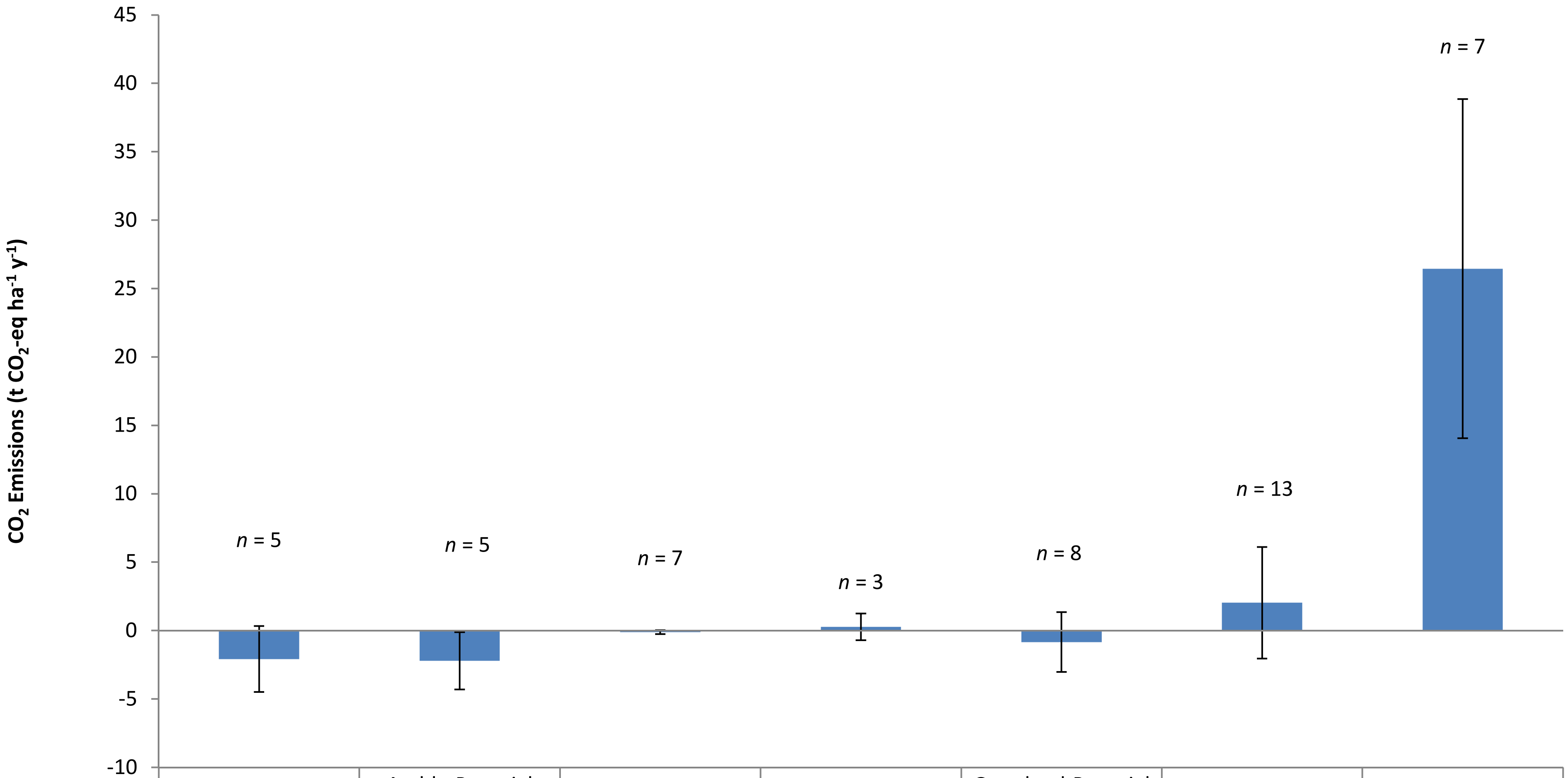

	Arable-SRC	Arable-Pernnial grasses	Arable-1st Gen	Grass-SRC	Grassland-Pernnial grasses	Grass-1st Gen	Forest-1st Gen
CO2 Emissions	-2.085	-2.214	-0.116	0.270	-0.841	2.029	26.450

Land use Transition

Figure 3.3: The effect of land-use change to bioenergy on CO_2 emissions. Standard deviation show with n denoting the number of observations. A positive value represents an emissions and a negative represents a sequestration event.

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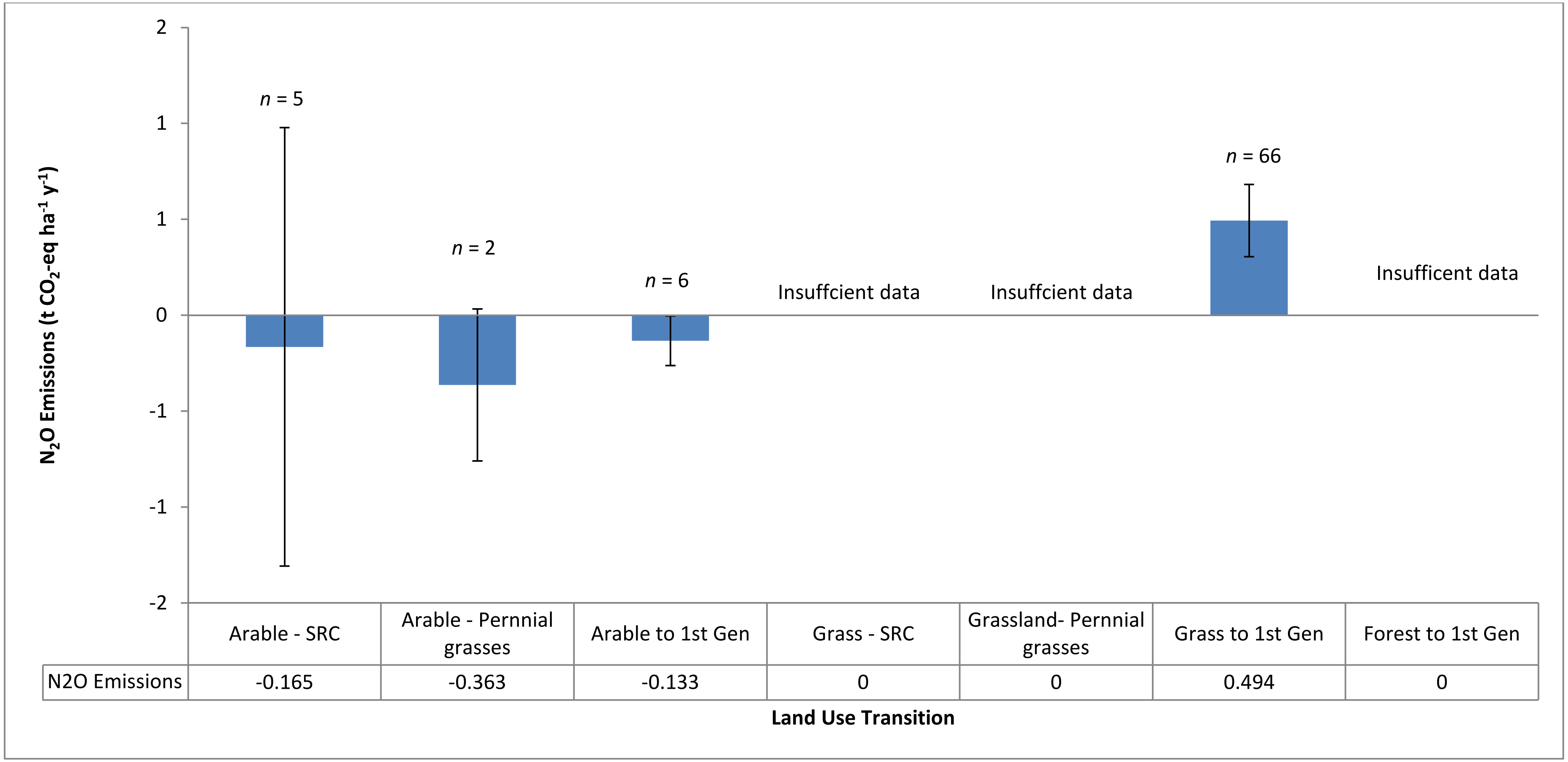

Figure 3.4: The effect of land-use change to bioenergy on N_2O emissions. Standard deviation show with n denoting the number of observations. A positive value represents an emissions and a negative represents a sequestration event.

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4. CONCLUSIONS AND FUTURE WORK

It is clear from the additional literature search in 2012 and 2013 that research activity is currently increasing in this area and is becoming more widely reported in the literature. Previous conclusions from this work emphasised the reliance on modelled and lookup table values; however, it has been observed there are more empirical studies now on-going, especially with the development of novel (and increasingly affordable) technologies, such as automated soil respiration systems and eddy covariance equipment.

Whilst there has been an increase in data available for this analysis there is still limited data on land use change to bioenergy in temperate regions. It is important that the reader understands that the meta-analysis still holds power despite a lack of statically significant results in this it is able to identify a trends in the effect of land use change to bioenergy and quantify their magnitude.

The summary in Table 4.1 shows that generally a transition from arable cropping to 2G bioenergy crops produced a reduction in GHG emissions and increased SOC, thus we can say with confidence that these are largely positive impacts. The transition from grassland to 2G crops is less certain with both positive and negative effects observed. And finally, a transition from forest to both 1G and 2G cropping results in decreased SOC and increased GHG emissions, thus a largely negative impact is likely for any bioenergy land use transition from tall forests. These conclusions are important in confirming the early pre-ELUM modelling work of ELUM partners (Aberdeen, Southampton and Forest Research) and provide further justification for the validation of the ELUM modelling approach through the collection of empirical data, which remains limiting.

Table 4.1: Summary of the effect on conversions to bioenergy cropping systems based on outputs from meta-analysis (SOC and TSC) and summary tables (GHG). Direction of arrow indicates the net direction of the fluxes; increase (↑), decrease (↓) or little to no change (↔). Colour of arrow indicates effect with green being positive, red negative and blue little to no change. A dash indicates where there were insufficient data. * indicates data were combined in the '2nd Gen' column. **Bold** text indicates a significant result.

Transition from:	Transition to:	SOC	TSC	GHG
Arable	SRC	↑**10.4%**↑	-*	↓CO_2↓N_2O↓
	Perennial grasses	↑6.4%↑	-*	↓CO_2↓N_2O↓
	1st gen	-	-	↔CO_2↔↓N_2O↓
	SRF	-	-	-
	2nd Gen	-	↑2.5%↑	-
Grass	SRC	-	-*	↔CO_2↔
	Perennial grasses	↓1.1%↓	-*	↓CO_2↓
	1st gen	-	-	↑CO_2↑N_2O↑
	SRF	-	-	-
	2nd Gen	-	↑3.2%↑	-
Forest	SRC	↓**28.2%**↓	-*	-
	Perennial grasses	-	-*	-
	1st gen	-	-	↑CO_2↑
	SRF	-	-	-
	2nd Gen	-	↓3.9%↓	-

This work, as well as that conducted in the other ELUM work packages, is extremely novel and will have a strong impact in the scientific domain, since a paired site approach for GHG fluxes has rarely been achieved and certainly not for a network of sites such as those being utilised in ELUM. Alongside the extensive chronosequence work conducted, and feed-in to models, this provides an outstanding opportunity for progress in this area and contribution towards the development of a sustainability framework based on evidence for these important land-use transitions. The recently published paper by Keith *et al.* (2014) will have a particular impact as it extensively covers transitions to SRF, including soil samples to depths greater than 30 cm, the importance of which was identified in deliverable D1.2.

5. REFERENCES

Borenstein, M., Hedges, L. V., Higgins, J. P. T. and Rothstein, H. R. (2009) Introduction to Meta-Analysis, John Wiley & Sons, Ltd, Chichester, UK.

Hillier J, Whittaker C, Dailey G *et al.* (2009) Greenhouse gas emissions from four bioenergy crops in England and Wales: Integrating spatial estimates of yield and soil carbon balance in life cycle analyses. GCB Bioenergy, **1**, 267-281

Keith AM, Rowe RL, Parmar K, Perks MP, Mackie E, Dondini M, McNamara NP (2014) Implications of land use change to Short Rotation Forestry in Great Britain for soil and biomass carbon. *GCB Bioenergy*, doi: 10.1111/gcbb.12168.

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Appendix I: Extended Methodology & Amendments from previously used methods

A1.1 Literature Search

In order to capture papers published since the last literature search, a modified strategy was used to that in D1.2, D1.3 and D1.5. Whilst in pervious deliverables three search engines were used to conduct the systematic search the decision was made to only use Web of Science (WOS). This decision was made in light of lessons learnt from the previous literature survey for 3 reasons:

1. Elsevier, which previously did not allow its publications to appear in Web of Science searches, has since changed and is covered under WOS. This means that there is no need to use Science Direct to acquire new publications as they will be captured by WOS.
2. Google scholar produced a very large amount of hits, the majority of which did not feed into the final analysis.
3. Web of Science is the industry standard when it comes to scientific publication and only publishes the highest quality peer-reviewed literature.

Whilst Google scholar proved to be a powerful search engine for researchers it is not wholly appropriate for this kind of systematic review as it captures a lot of nonsensical hits and not necessarily the most up-to-date literature.

It is, therefore, recommended that in an exercise such as this, Web of Science is searched systematically using the defined search terms followed by the selective use of Google Scholar for the capture of any grey literature, should that be within the scope of the review.

A1.2 Meta-Analytical Methods

Due to the power of a meta-analysis and the conclusions that can be drawn from such an analysis, it is essential to ensure that data are appropriate for such techniques, enabling robust conclusions to be drawn. We concluded that only data with an associated error term should be used for a robust meta-analysis – thus data from model simulations and LCA were not used in this study, in contrast to the preliminary analysis submitted in D1.5. Though initially these data were bootstrapped* and presented we are concerned that this approach may be questionable in the peer-reviewed literature and thus here, have considered only data sets with their own error term. This is a major limitation since few data sets on land use transitions are available in the context of 2G bioenergy crops.

In order to perform a meta-analysis three key values are needed, a mean ($\bar{x}$), a standard deviation (SD) and a sample size (n). And in order to assess the relative effect of a change from one land use to another, a starting value is required, enabling a pre-land use change estimate of soil properties and GHG balance and a post-conversion estimate to be used. Where either error terms or a pre-land use value were unavailable, authors were contacted for additional information. Where these data remained unavailable, strict meta-analysis techniques could not be used and thus, much useful information was lost from the meta-analysis but is still relevant to the narrative review being developed (draft paper in progress).

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In the previous deliverable, Hedge's G was used as an estimator of the effect size, however the effect size can be difficult to interpret as the value requires explanatory text to allow it to be fully understood. A more intuitive effect size, more commonly used in ecology, is the Log Response Ratio (ln(R)) as measures are on a physical scale and possess a natural zero point. The other advantage of using ln(R) is the ability to transform the effect size into a percentage change therefore bringing an ease of interpretation to the reader. The calculation of the effect size and transformation into a percentage can be seen in equations 2.1 and 2.2.

$$lnR = ln(R) = ln\left(\frac{\bar{X}_1}{\bar{X}_2}\right) = ln(\bar{X}_1) - ln(\bar{X}_2)$$

(2.1)

$$\%\, change = (exp(lnR) - 1)x\ 100$$

(2.2)

SOC data was extracted from 6 additional papers and for TSC, data was extracted from 4 additional papers, each observation was entered as a 'study'. For both SOC and TSC, there were sufficient data to conduct a meta-analysis on certain transitions. The meta-analysis was conducted in R, as the software package used previously in report D1.5, CMA, was unable to compute ln(R). A test for publication bias was conducted for each of the analyses by plotting a funnel plot of the log ratio of the means against the standard error. The presence of symmetry in all the plots indicated little to no publication bias (Appendix I).

There were insufficient data to conduct a meta-analysis on the effect of land use change to bioenergy on GHG emissions. Therefore, with the data that were extracted, an arithmetic mean, SD and sample size were taken and presented in a standard histogram. There were sufficient data to assess the effects on CO_2 emissions and N_2O emissions, but there were insufficient data for some transitions and for the effect on CH_4 emissions. A total of 21 papers contributed to this part of the analysis.

*Bootstrapping is a statistical resampling technique which allows generation of a mean, standard error and 95% confidence limits.

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Appendix II: Testing for Publication Bias

Publication bias is a well-known issue in meta-analyses and arises as a result of the fact that studies reporting higher effect sizes or significant results are more likely to be published than those reporting lower effect sizes or results that are not statically significant (Borenstein *et al.*, 2009). This problem is applicable to narrative reviews also but is more noteworthy in meta-analyses as these are seen to be more accurate and reliable than traditional narrative reviews. Publication bias therefore can lead to an overestimation of the effect size. One way of detecting if there is publication bias in a meta-analysis is to plot the log of the effect size along x-axis with the standard error along the y-axis, which is known as a funnel plot. If publication bias is present, there will be asymmetry or clustering in the funnel plot, a lack of publication bias can be seen in figure A2.1 - A2.4 due to symmetry across the plot.

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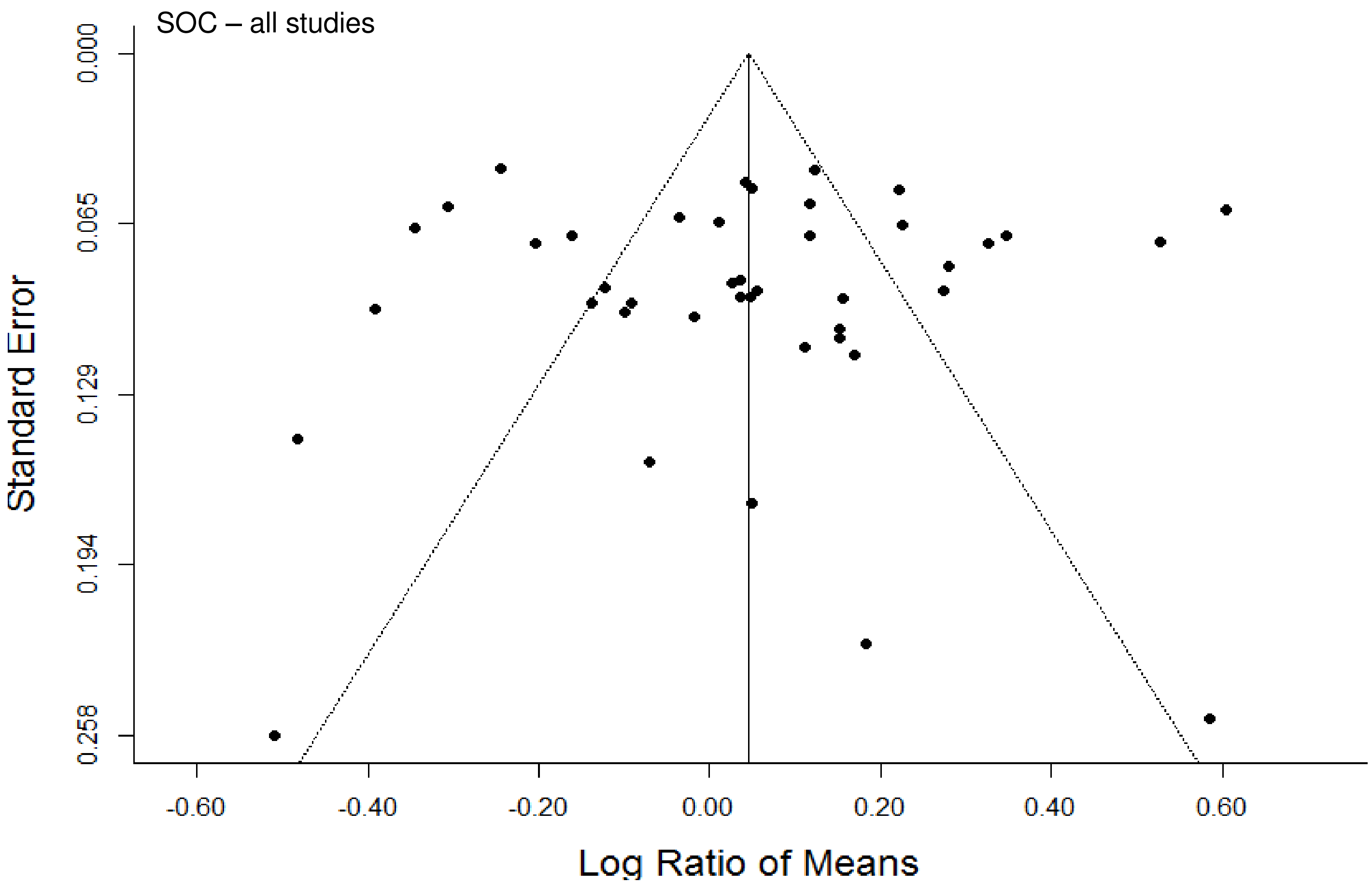

Figure A2.1: Testing for publication bias across all studies in the SOC meta-analysis. The presence of symmetry within the funnel plot indicates little or no publication bias.

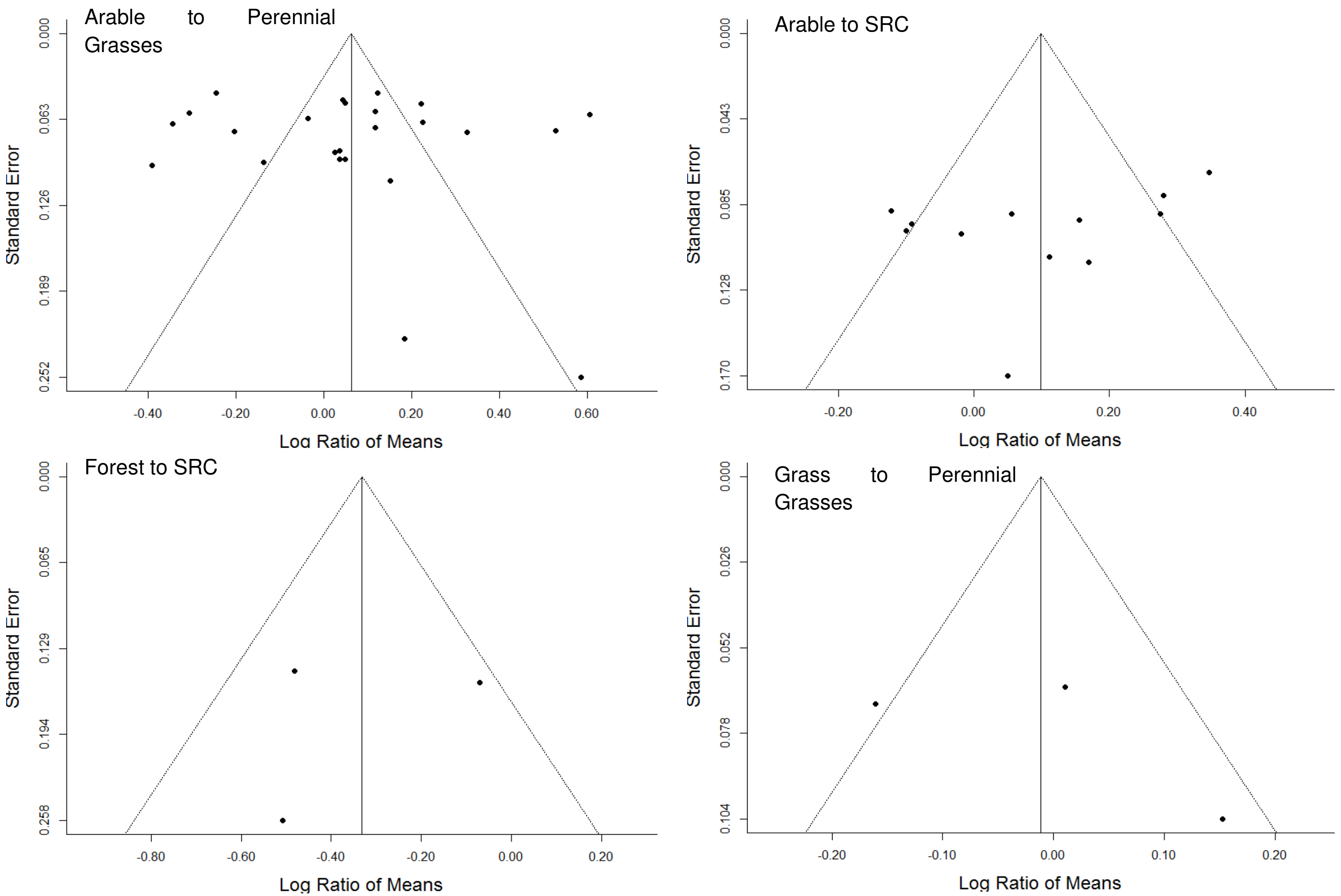

Figure A2.2: Testing for publication bias across individual SOC transitional meta-analyses. The presence of symmetry within the funnel plot indicates little or no publication bias.

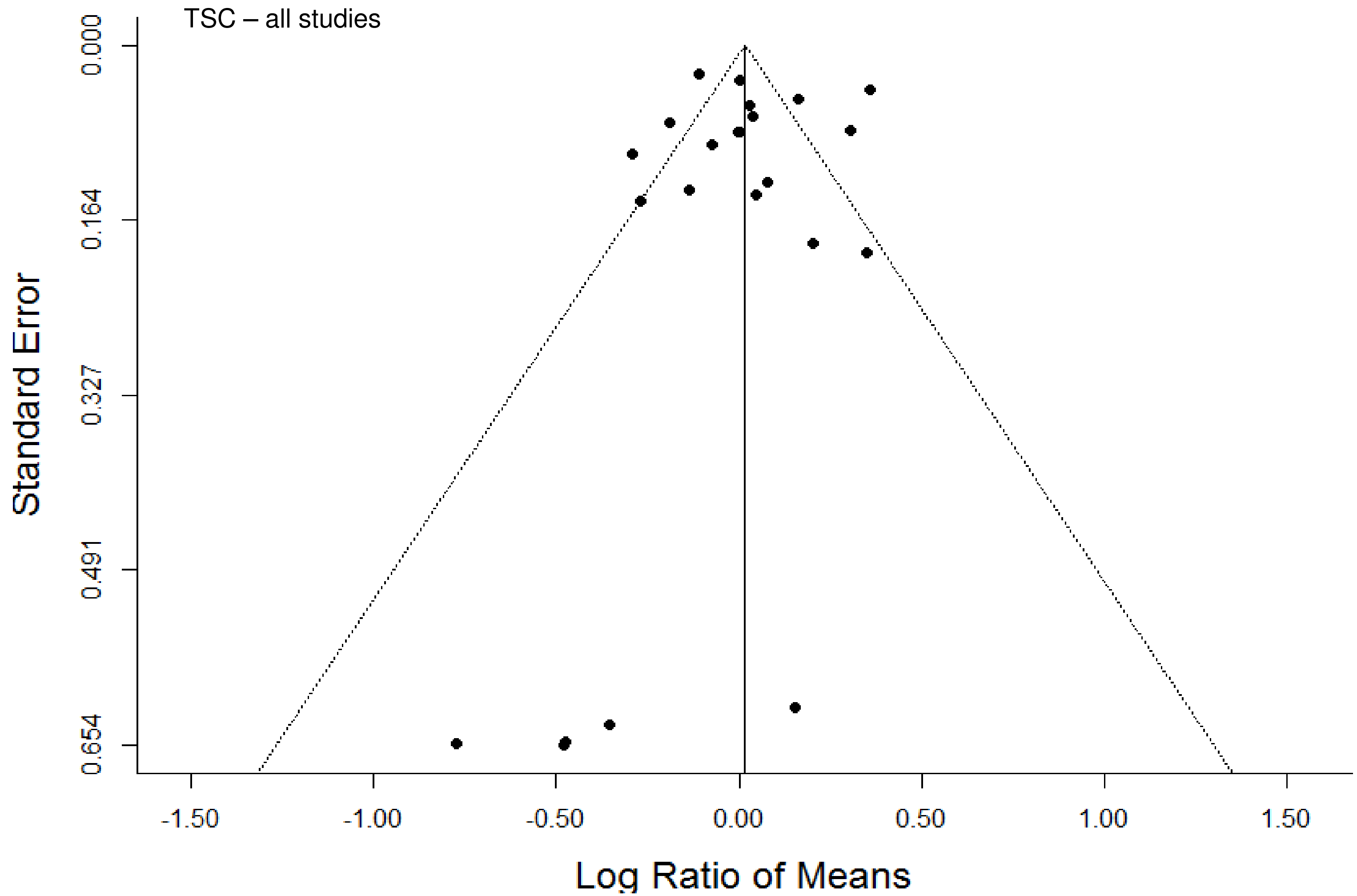

Figure A2.3: Testing for publication bias across all studies in the TSC meta-analysis. The presence of symmetry within the funnel plot indicates little or no publication bias.

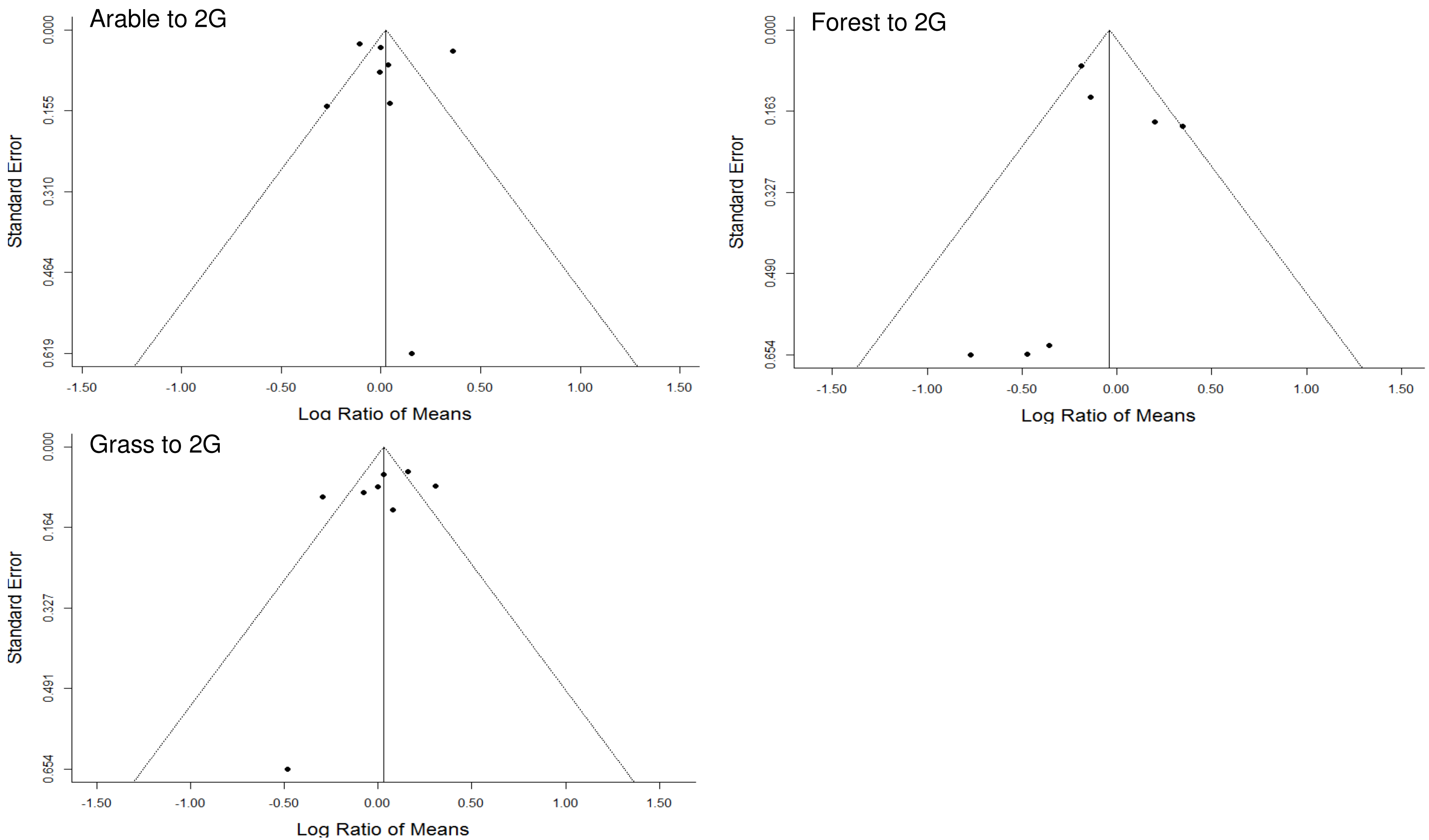

Figure A2.4: Testing for publication bias across individual TSC transitional meta-analyses. The presence of symmetry within the funnel plot indicates little or no publication bias.

Appendix III: Total number of papers and studies used in analysis

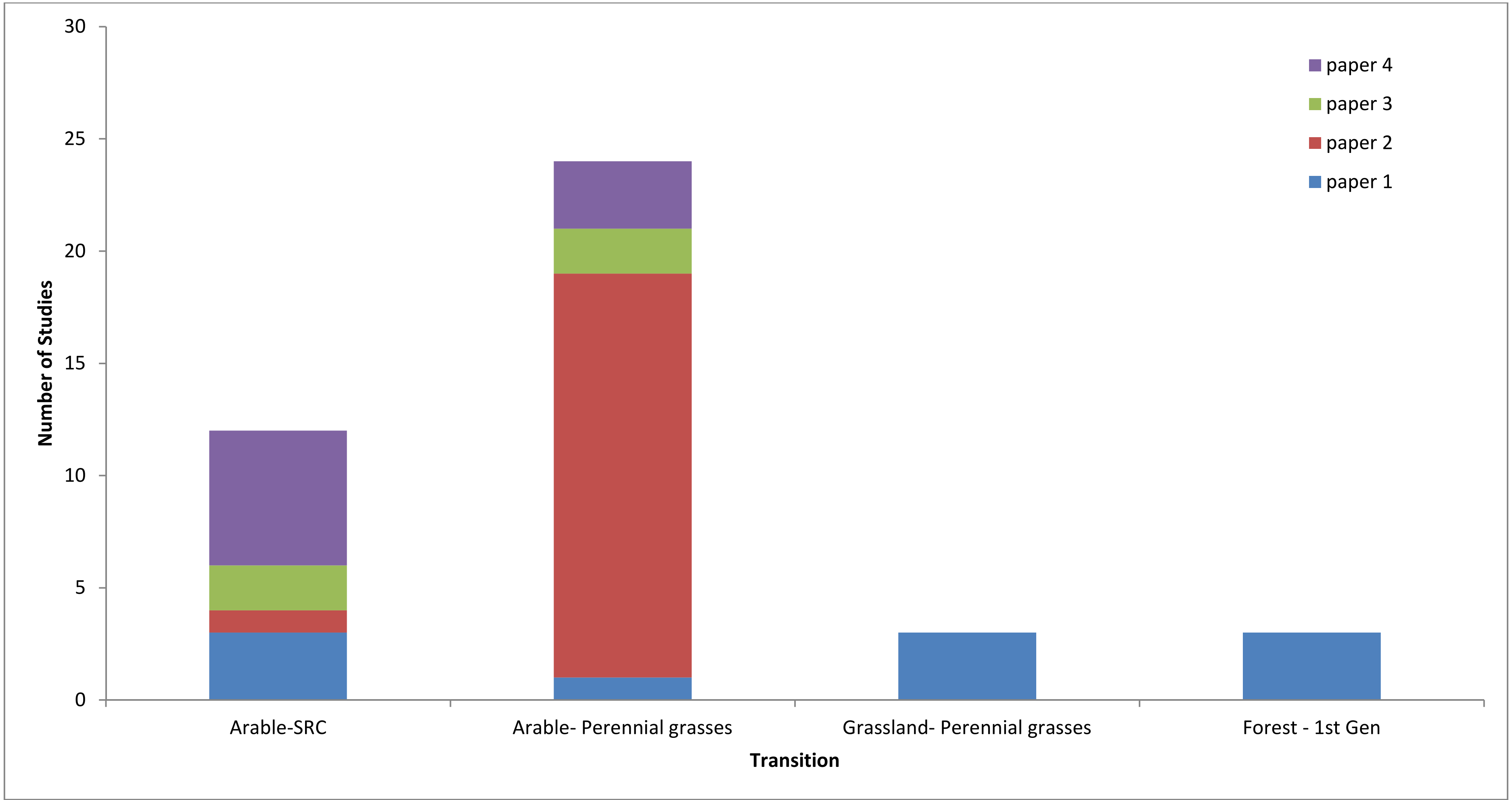

Figure A3.1: Total number of papers and studies from each paper which contributed to meta-analysis on the effect of a land use transition to bioenergy on soil organic carbon (SOC).

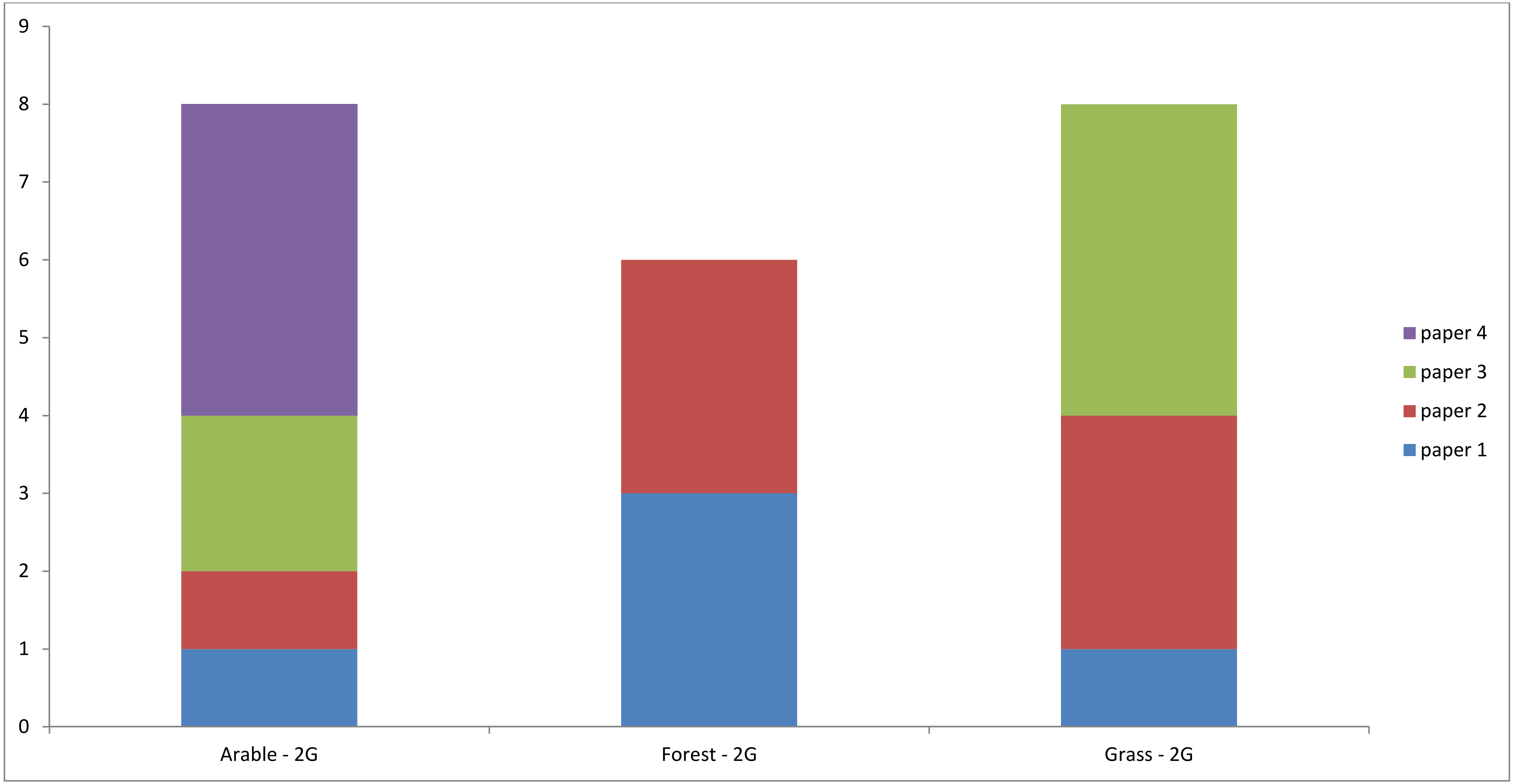

Figure A3.2: Total number of papers and studies from each paper which contributed to meta-analysis on the effect of a land use transition to bioenergy on total soil (TSC).

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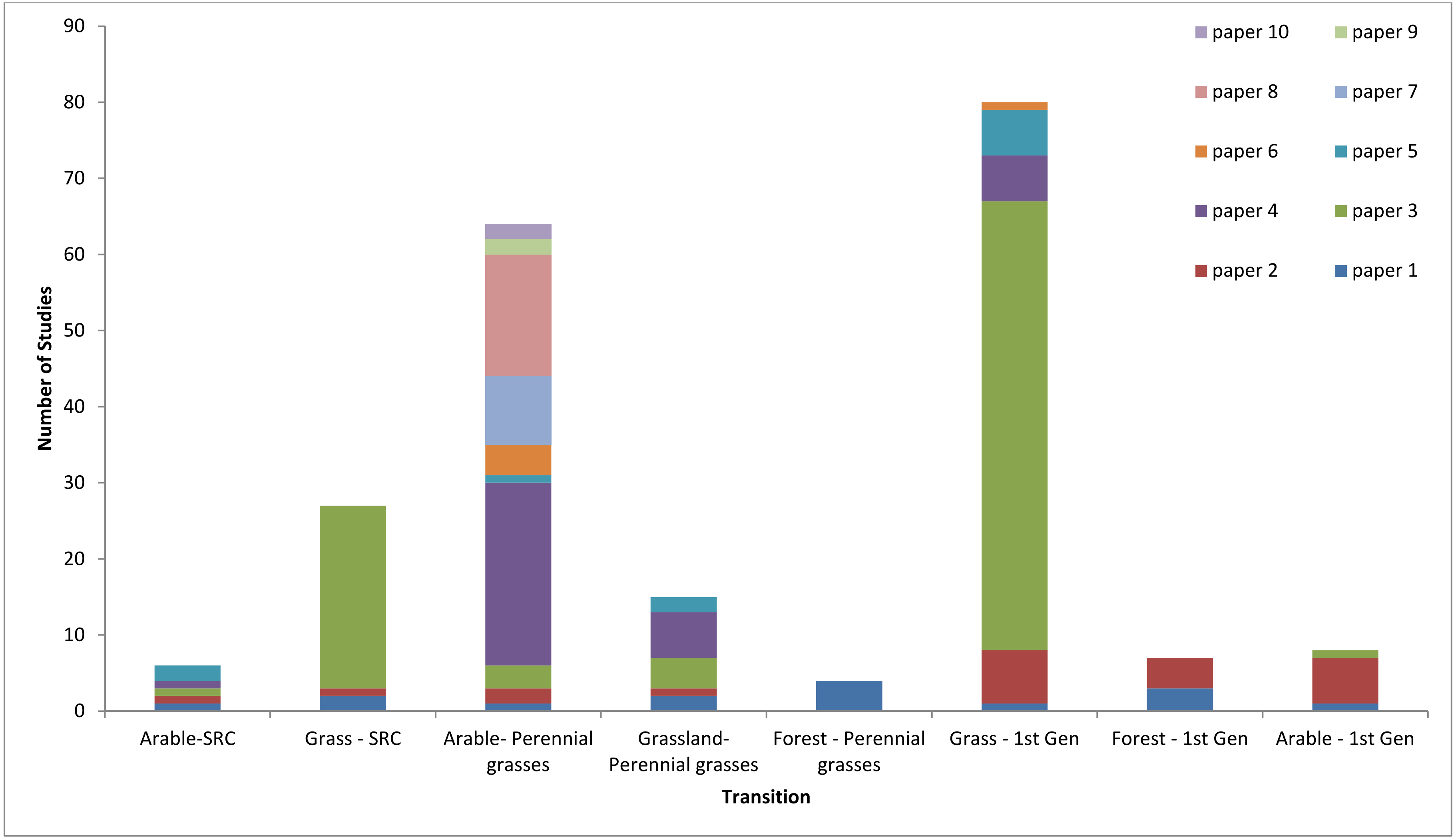

Figure A3.3: Total number of papers and studies from each paper which contributed to a summary table on the effect of a land use transition to bioenergy on greenhouse gases (GHG).

Appendix IV: Meta-analysis forest plots in Ln(R)

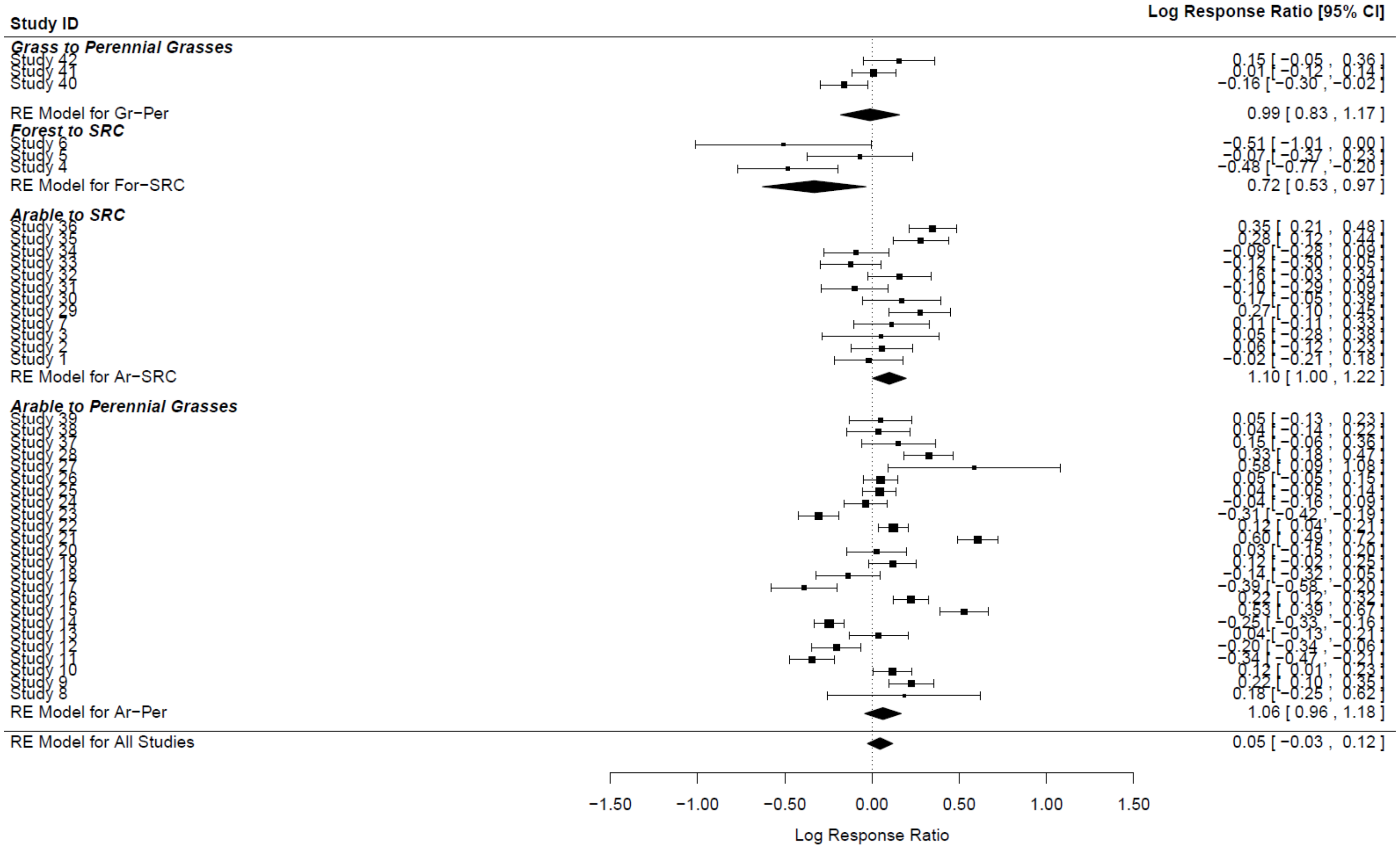

Figure A4.1: The effect of land-use change to bioenergy crops on soil organic carbon (SOC). Log response ratio ln(R) presented using a random effects model. Individual study data and summary effect size polygons are shown with 95% confidence intervals.

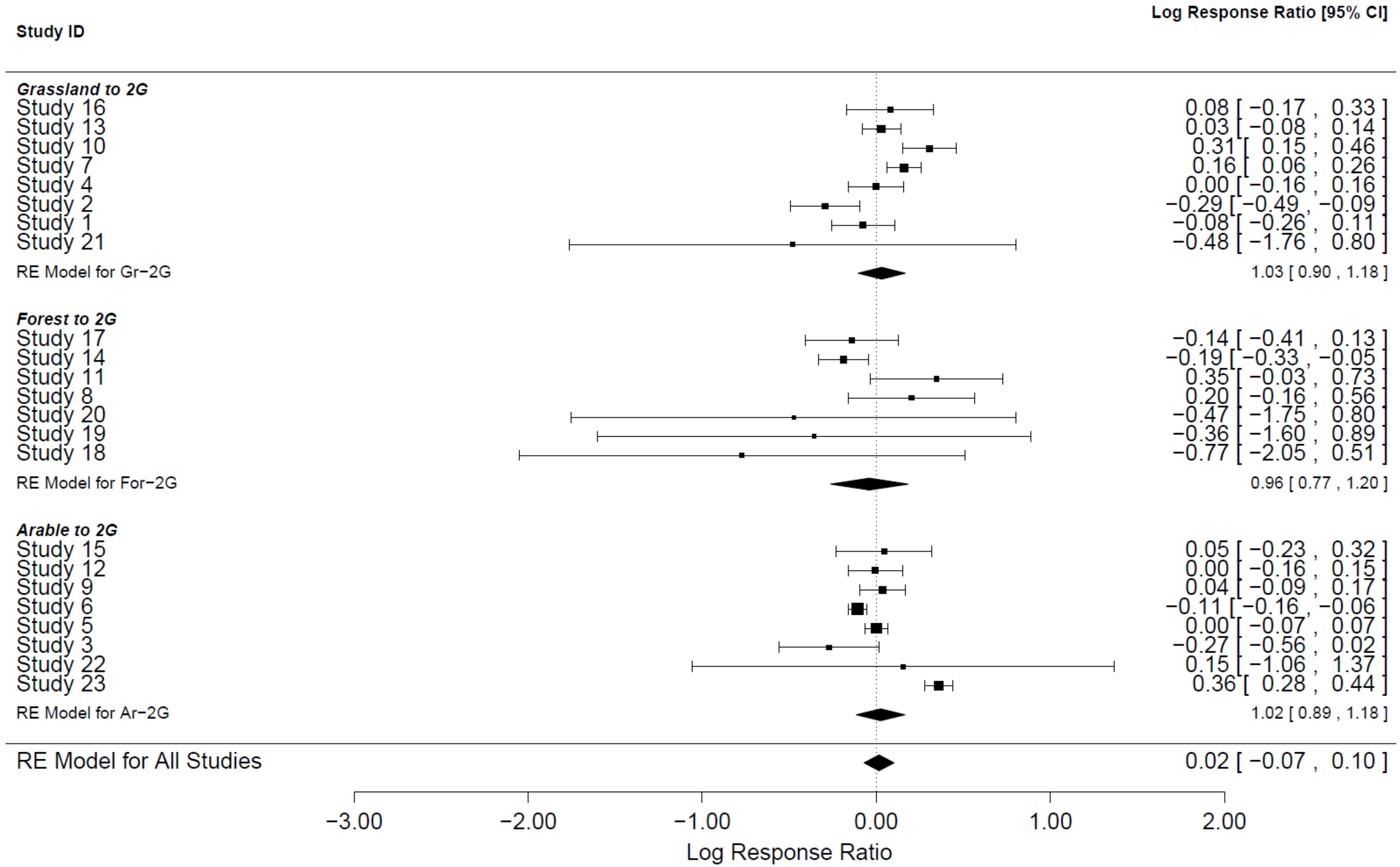

Figure A4.2: The effect of land-use change to bioenergy crops on total soil carbon (TSC). Log response ratio ln(R) presented using a random effects model. Individual study data and summary effect size polygons are shown with 95% confidence intervals.

Appendix V: References used in Meta-analysis & summary tables

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