Standardized ileal digestible methionine and cysteine requirement for broilers

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CVB Documentation report nr. 63
June 2018

https://doi.org/10.18174/455513

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Preface

In 2017 a new Table has been introduced called; Table 'Standardized ileal digestibility of amino acids in feedstuffs for poultry' and has been described in the CVB Documentation report nr. 61. As a feed evaluation system has two pillars – the supply of nutrients by the diet on the one hand and the requirement for these nutrients by the animals on the other hand (both expressed in the same units) – it was also necessary to also update and express the amino acid requirements on a standardized ileal digestibility (SID) basis.
Therefore a large meta-analysis dataset was constructed from studies in which amino acid requirements in broilers were estimated. The SID amino acid concentrations of the diets used in the studies were recalculated based on the new CVB SID amino acid Table (CVB Documentation report nr. 61) and requirements of SID amino acids were subsequently estimated. The results of this meta-analysis for standardized ileal digestible methionine and cysteine (SID-M+C) are presented in the present CVB Documentation report. Compared to the former CVB apparent faecal digestible M+C recommendation for broilers described in CVB Documentation report nr. 18 and published in 1996 the present established SID-M+C amino acid recommendations for broilers are:

1. Based on a substantial larger dataset of requirement studies
2. Based on studies with modern broiler types in the period 1989 – 2017
3. Based on standardized ileal digestible amino acid values in feedstuffs instead of apparent faecal digestible amino acid values.

The in this report estimated requirement of SID-M+C will be incorporated in the Dutch CVB Tabellenboek Veevoeding Pluimvee 2018 and in the English version CVB Table Poultry Nutrition 2018.

This study was guided and assessed by the Technical Committee of CVB

Wageningen, June 2018

J.W. Spek

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Abbreviations

AA	Amino acids
AFD	Apparent faecal digestible
ARG	Arginine
BWG	Body weight gain
CP	Crude protein
FCR	Feed conversion ratio
ILE	Isoleucine
LYS	Lysine
ME	Metabolic energy
MET	Methionine
M+C	Methionine plus Cysteine
N	Number
R^2	Coefficient of determination
Req	Requirement
SID	Standardized ileal tract digestible
Std. Dev.	Standard deviation
Std. Err.	Standard error
THR	Threonine
TRP	Tryptophan
VAL	Valine

1 Introduction

In 2012 a large meta-analysis was carried out by Veldkamp and others in order to determine the dietary requirements for standardized ileal tract digestible (SID) amino acids (AA) for broilers. This study resulted in a report published by Veldkamp et al. (2016). Before the start of this meta-analysis another large meta-analysis was carried out in order to determine the SID-AA levels for the various feed ingredients. This meta-analysis resulted in a CVB table with SID-AA concentrations for the various feed ingredients and this Table was used by Veldkamp et al. (2016) in order to recalculate the dietary SID-AA levels for the individual AA titration studies in order to estimate AA requirements. However, in 2017 this CVB Table has been updated with new data published in the years between 2012 and 2017 as there were questions about the SID cysteine digestibility value for soybean meal. As a result, not only the SID-AA values for soybean meal have been updated but also for other feedstuffs. As a consequence it was necessary to recalculate all the diets used in the AA titration studies that Veldkamp et al. (2016) used to determine AA requirements. In this CVB documentation report the results of estimated dietary SID methionine and cysteine (SID-M+C; %) requirements are presented that are based on the new Table values as presented in CVB documentation report nr. 61. Furthermore, the dataset used by Veldkamp et al. has been extended with new studies that were not included in the study of Veldkamp et al.. This resulted in a dataset that is substantially larger than the dataset used by Veldkamp. The SID-M+C requirements of the individual titration trials were estimated using a quadratic broken line model. This model was also used in estimation of SID-lysine requirements in the individual lysine titration trials as described in CVB documentation report nr. 62.

2 Materials and Methods

Methionine and cystine titration studies were selected from literature (1989 – 2017) in which only the dietary M+C content was varied by means of addition of graded levels of dietary synthetic methionine and/or cysteine. Furthermore, only those titration studies were selected in which non-test apparent digestible amino acid levels of the basal diet (diet with the lowest M+C content) did not come below 10% of the recommended CVB (2012) levels and where dietary digestible M+C levels of the basal diets where at least 20% below the recommended CVB (2012) level. Furthermore, performance characteristics such as body weight gain (BWG: g/d) and feed conversion ratio (FCR; g feed : g BWG) had to be recorded and information with respect to dietary composition, sex, age of the broilers and duration of the experiment had to be provided in the studies.

Requirements were estimated using a quadratic broken-line model. The quadratic broken line model is as follows:

If (SID-M+C (%) < R) then BWG or FCR = L + U × (R – SID-M+C)$^{\wedge 2}$;
Else BWG or FCR = L + U × 0;
Where:
L = plateau value for BWG or FCR
R = break-point value for SID-M+C (%)
U = slope value, representing the increase in BWG or decrease in FCR per unit increase in dietary SID-M+C.

As M+C requirements are normally expressed as a percentage of lysine (LYS) requirement the estimated SID-M+C requirements of the individual M+C titration trials were expressed as a percentage of SID-LYS level. The SID-LYS level was in a number of cases the SID-LYS level used in the M+C titration studies. However, in a number of cases the SID-LYS levels used in the M+C titration studies were larger than the SID-LYS requirements as predicted from the factors mean age of the birds and the dietary ME value as described in the prediction formulas F.5. and F.9. in CVB documentation report nr. 62. In those cases where the SID-LYS levels used in the M+C titration studies were larger than the SID-LYS requirements as predicted from the prediction formula for SID-LYS requirements in CVB documentation report nr. 62 the predicted SID-LYS requirement levels using formulas F.5. (for BWG) and F.9. (for FCR) were used for the calculation of the SID M+C : SID-LYS ratios (SID-M+C:LYS) of the individual experiments.

Via the PROC MIXED procedure of SAS the estimated SID-M+C:LYS requirements for BWG and FCR were regressed against factors such as age, sex and the dietary factors CP, ME and CP : ME ratio with study effect included as a random factor. Furthermore, non-test SID-AA : SID-LYS ratios were calculated and it was checked whether some of the non-test SID AA negatively affected the estimated SID-M+C:LYS requirement levels.

3 Results and Discussion

In Table 1 a summary of the total dataset is given. The dataset consisted of 15 studies with in total 60 titration trials and 328 observations.

Table 1. Summary of the total dataset

	N	Mean	Std. Dev.	Minimum	Maximum
ME Recalculated (kcal/kg)	328	3035	123.0	2785	3360
ME Publication (kcal/kg)	328	3114	103.9	2950	3370
CP Recalculated (%)	328	21	1.6	18	28
CP Publication (%)	328	21	1.7	17	28
Year	328	2007	7.1	1989	2016
Starting age (d)	328	10	9.1	1	36
Duration (d)	328	14	5.3	6	21
finishing age (d)	328	24	11.9	7	42
Mean age (d)	328	17	10.2	4	39
BWG (g/d)	328	49.3	24.16	7.7	125.8
FCR	328	1.591	0.3821	1.001	2.778

In Appendix A for each titration trial the relationship between dietary SID-M+C supply and FCR and the relationship between dietary SID-M+C and BWG is presented graphically together with the estimated requirement values. In Appendix B the estimated quadratic broken-line model parameters for each titration trial is given.

For a number of titration trials (13 titration trials for FCR and 14 titration trials for BWG) it was not possible to estimate reliable or unique SID-M+C requirements.
The estimated SID-M+C:LYS requirement ratios for BWG and FCR were not significantly related to sex and age. Furthermore, dietary protein concentration was significantly related to the estimated SID-M+C:LYS requirement for BWG but not to the estimated SID-M+C:LYS requirement for FCR. Dietary ME was significantly and positively related to SID-M+C:LYS requirement ratios for both BWG and FCR. The ratio of dietary protein to dietary ME could not explain more variation in SID-M+C:LYS requirement than dietary ME content alone. The amount of variation in estimated SID-M+C:LYS requirement for BWG explained by dietary protein content was low (R^2 = 0.118) and also the amount of variation in SID-M+C:LYS for BWG and FCR explained by dietary ME content was low (R^2 = 0.283 and 0.125 for, respectively, BWG and FCR).

Because only a marginal amount of variation in SID-M+C:LYS requirement for BWG and FCR could be explained by factors such as dietary protein and dietary ME and because the factors sex and age were not significant in explaining variation in SID-M+C:LYS requirements for BWG and FCR it was concluded that it is undesirable to predict SID-M+C:LYS requirement ratios based on factors such as age, sex, dietary protein content and dietary ME content.

The average estimated SID-M+C:LYS ratios for the remaining 47 estimated SID-M+C:LYS requirement values for FCR and the 46 estimated SID-M+C:LYS requirement values for BWG were:

SID-M+C:LYS for BWG = 71.4±9.55 % (average ± Std. Dev.)
SID-M+C:LYS for FCR = 71.7±11.81 % (average ± Std. Dev.)

Furthermore, there were some outlier SID-M+C requirement estimates that deviated more than two standard deviations from the average estimated SID-M+C requirement estimates. These were 2 estimated values from the study of Fatufe and Rodehutscord (2005) (low estimated SID-M+C requirement values for both BWG and FCR), 2 estimated requirement values from the study of Dozier and Mercier (2013), and one estimated requirement value from the study of Lumpkins et al. (2007).

When removing these outlier values the average estimated SID-M+C:LYS requirement ratios for the remaining 43 FCR trials and 42 BWG trials were:

SID-M+C:LYS for BWG = 71.8±7.36 % (average ± Std. Dev.)
SID-M+C:LYS for FCR = 72.1±8.29 % (average ± Std. Dev.)

There were some studies that contained a large number of titration trials whereas some studies contained only one titration trial. This results in average calculated SID-M+C:LYS requirement ratios for BWG and FCR that were strongly influenced by the studies containing a large number of titration trials. In order to weigh the estimated SID-M+C:LYS ratios from each study equally it is necessary to take into account the effect of study. This was done (using the PROC MIXED procedure of SAS and by including study as a random effect in the model) and then the estimated SID-M+C:LYS ratios for BWG and FCR became:

SID-M+C:LYS for BWG = 71.9±2.61 % (model estimate ± Std. Err.)
SID-M+C:LYS for FCR = 72.1±3.22 % (model estimate ± Std. Err.)

In Table 2 the dietary non-test SID-AA : SID-LYS requirement ratios for FCR and BWG are given together with the recommended CVB apparent faecal digestible (AFD) ratios. Results in Table 2 show that on average the estimated SID-M+C requirement estimates were not negatively impacted by limiting non-test AA levels although in a number of trials some non-test AA levels could have had a negative impact on estimated SID-M+C levels as a comparison between recommended CVB ratios and minimal ratios for both FCR and BWG observed in this study show. However, a visual inspection of graphs in which the various SID-AA:LYS ratios were plotted against estimated SID-M+C:LYS requirements did show only one study with two titration trials (study of Fatufe and Rodehutscord, 2005) in which the estimated SID-M+C:LYS requirements substantially differed from the rest of the SID-M+C requirement estimates combined with suboptimal low ratios of non-test AA:LYS ratios of TRP:LYS, ILE:LYS en LEU:LYS.

Table 2. Dietary non-test SID-AA : SID-LYS ratios.for FCR and BWG and compared to the recommended (Rec.) CVB apparent faecal digestible (AFD) ratios.

Ratio	**Rec. CVB AFD ratio**	**FCR**				**BWG**			
		Mean	**Std. Dev.**	**Min**	**Max**	**Mean**	**Std. Dev.**	**Min**	**Max**
THR:LYS	65	63	5.0	46	70	64	4.9	46	70
TRP:LYS	16	18	2.9	12	21	18	3.0	12	21
ILE:LYS	66	70	8.5	43	80	70	8.4	43	80
ARG:LYS	105	115	14.0	88	177	115	14.0	88	177
VAL:LYS	80	79	6.5	60	89	80	6.4	60	88

The exercise of estimating SID-M+C:LYS requirement ratios for BWG and FCR in which each study is equally weighted was now repeated but in this case the results of the study of Fatufe and Rodehutscord (2005) were excluded. When this was done (by using the PROC MIXED procedure of SAS and including study as a random effect in the model) the estimated SID-M+C:LYS requirement ratios for BWG and FCR became:

SID-M+C:LYS for BWG = 73.2±1.70 % (model estimate ± Std. Err.)
SID-M+C:LYS for FCR = 74.3±2.28 % (model estimate ± Std. Err.)

It furthermore appeared that the estimated SID-M+C:LYS ratios were related to the model estimated increase in BWG per unit increase in dietary SID-M+C as shown in Figure 1. Figure 1 shows a model estimated SID-M+C:LYS plateau ratio of around 66% at steep increases in BWG per unit increase in dietary SID-M+C. This ratio increases up to a estimated SID-M+C:LYS ratio of 95% at very low model estimated increases in BWG per unit increase in dietary SID-M+C. The model estimated increase in BWG per unit increase in dietary SID-M+C was also related to the difference between the basal level of BWG and the estimated maximum BWG (= L) as shown in Figure 2 indicating that choice of the basal level of dietary SID-M+C in a titration study affects the estimated SID-M+C:LYS ratio (the lower the basal level, the higher the difference between the basal level of BWG and the estimated maximum BWG (= L) and the lower the estimated SID-M+C:LYS ratio). These relationships suggest that a SID-M+C:LYS ratio of around 66% is the absolute minimum requirement for SID-M+C resulting in a strong impairment of BWG below 66% whereas small improvements in BWG may be expected at SID-M+C:LYS ratios above 66%.

It can be concluded that variation in estimated SID-M+C:LYS ratios was not sufficiently related to sex, age and dietary energy and protein to develop a prediction formula for SID-M+C:LYS based on one of the just named factors. It is furthermore concluded that part of the variation in estimated SID-M+C:LYS ratios is related to the model estimated steepness of the increase in BWG per unit increase in dietary SID-M+C and that this steepness is affected by the choice of the basal level of M+C in the diet (the lower the basal level, the higher the difference between BWG at the basal level and the estimated plateau level, the steeper the increase in in BWG per unit increase in dietary SID-M+C, and the lower the estimated SID-M+C:LYS ratio).

It is therefore difficult to decide what the optimal dietary SID-M+C:LYS ratio is. Because of this difficulty it might be most prudent to base the dietary SID-M+C:LYS ratio recommendation on the complete dataset of SID-M+C trials and correct for a (random) study effect. This results in the following recommendations:

SID-M+C:LYS for BWG = 73.2±1.70 % (model estimate ± Std. Err.)
SID-M+C:LYS for FCR = 74.3±2.28 % (model estimate ± Std. Err.)

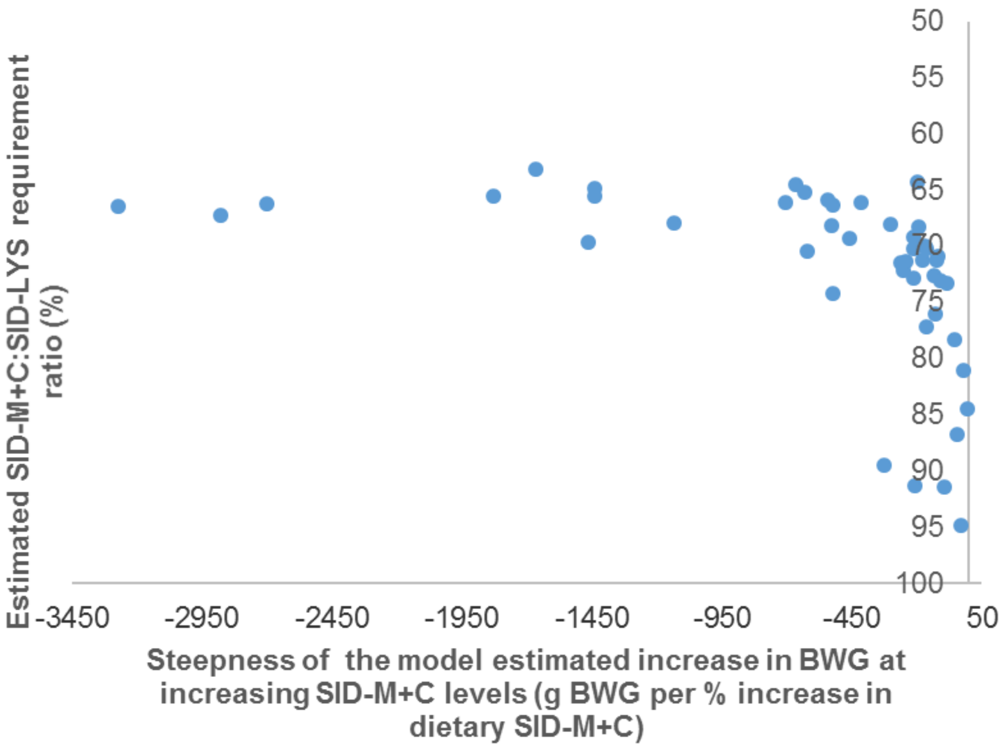

Figure 1. Relationship between the estimated SID-M+C:SID-LYS requirement ratio (%) and the model estimated steepness of the increase in BWG at increasing dietary SID-M+C levels (g BWG per percent increase in dietary SID-M+C).

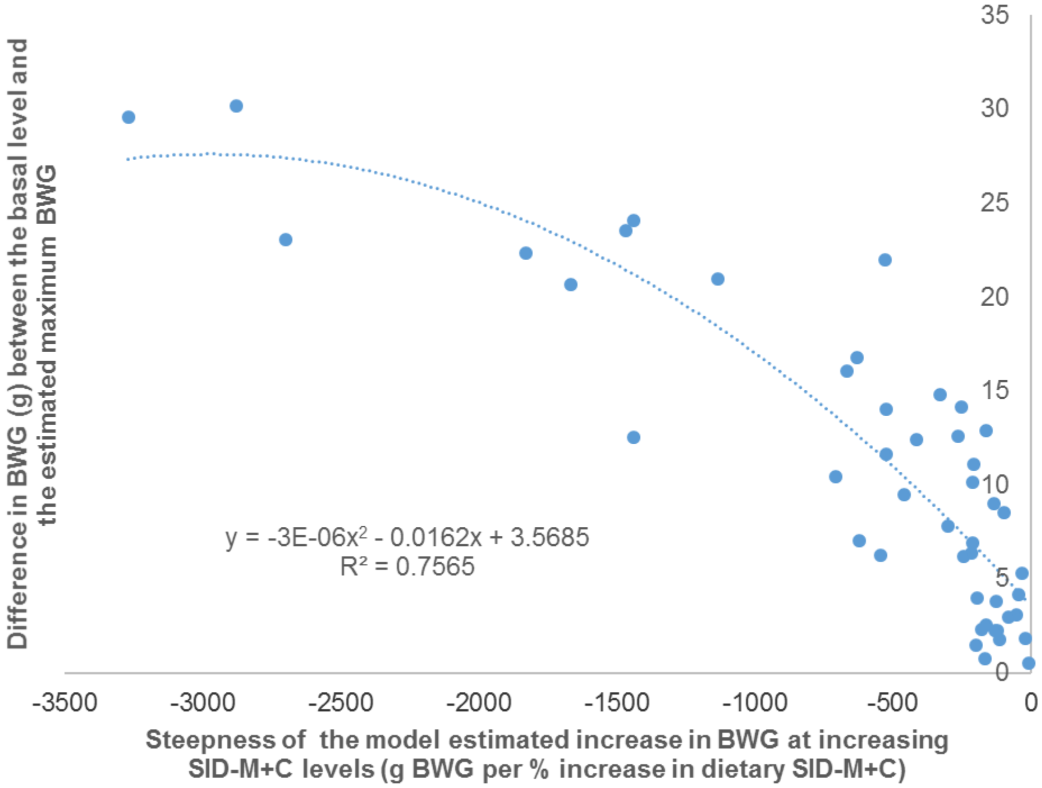

Figure 2. Relationship between the difference in BWG (g) between the basal diet and the estimated maximum BWG and the modelled steepness of the increase in BWG at increasing dietary SID-M+C levels (g BWG per percent increase in dietary SID-M+C).

4 Conclusions

Based on the results of this study it is concluded that it is most prudent to base the dietary SID-M+C:LYS ratio recommendation on the complete dataset of SID-M+C trials and correct for a (random) study effect. This results in the following SID-M+C:LYS requirements:

SID-M+C:LYS for BWG = 73 %
SID-M+C:LYS for FCR = 74 %

List of studies included in the meta-analysis

Agostini, P. S., P. Dalibard, Y. Mercier, P. Van Der Aar, and J. D. Van Der Klis. 2016. Comparison of methionine sources around requirement levels using a methionine efficacy method in 0 to 28 day old broilers. Poultry Science 95(3):560-569.

Albino, L. F. T., S. H. M. Da Silva, J. G. Vargas Jr, H. S. Rostagno, and M. De Almeida E Silva. 1999. Methionine + Cystine Levels for Broilers from 1 to 21 and from 22 to 42 Days of Age. Revista Brasileira de Zootecnia 28(3):519-525.

Baker, D. H., S. R. Fernandez, D. M. Webel, and C. M. Parsons. 1996. Sulfur amino acid requirement and cystine replacement value of broiler chicks during the period three to six weeks posthatching. Poultry Science 75(6):737-742.

Chamruspollert, M., G. M. Pesti, and R. I. Bakalli. 2002. Determination of the methionine requirement of male and female broiler chicks using an indirect amino acid oxidation method. Poultry Science 81(7):1004-1013.

Chamruspollert, M., G. M. Pesti, and R. I. Bakalli. 2004. Influence of temperature on the arginine and methionine requirements of young broiler chicks. Journal of Applied Poultry Research 13(4):628-638.

Dozier Iii, W. A. and Y. Mercier. 2013. Ratio of digestible total sulfur amino acids to lysine of broiler chicks from 1 to 15 days of age. Journal of Applied Poultry Research 22(4):862-871.

Fatufe, A. A. and M. Rodehutscord. 2005. Growth, body composition, and marginal efficiency of methionine utilization are affected by nonessential amino acid nitrogen supplementation in male broiler chicken. Poultry Science 84(10):1584-1592.

Goulart, C. D. C., F. G. P. Costa, J. H. V. da Silva, J. G. de Souza, V. P. Rodrigues, and C. F. S. de Oliveira. 2011. Requirements of digestible methionine + cystine for broiler chickens at 1 to 42 days of age. Revista Brasileira de Zootecnia 40(4):797-803.

Kalinowski, A., E. T. Moran Jr, and C. L. Wyatt. 2003. Methionine and cystine requirements of slow- and fast-feathering broiler males from three to six weeks of age. Poultry Science 82(9):1428-1437.

Lumpkins, B. S., A. B. Batal, and D. H. Baker. 2007. Variations in the digestible sulfur amino acid requirement of broiler chickens due to sex, growth criteria, rearing environment, and processing yield characteristics. Poultry Science 86(2):325-330.

Mack, S., D. Bercovici, G. De Groote, B. Leclercq, M. Lippens, M. Pack, J. B. Schutte, and S. Van Cauwenberghe. 1999. Ideal amino acid profile and dietary lysine specification for broiler chickens of 20 to 40 days of age. British Poultry Science 40(2):257-265.

Mendonca, C. X. and L. S. Jensen. 1989. Influence of protein concentration on the sulphur-containing amino acid requirement of broiler chickens. British Poultry Science 30(4):889-898.

Rakangtong, C. and C. Bunchasak. 2011. Effect of total sulfur amino acids in corn-cassava-soybean diets on growth performance, carcass yield and blood chemical profile of male broiler chickens from 1 to 42 days of age. Animal Production Science 51(3):198-203.

Shen, Y. B., P. Ferket, I. Park, R. D. Malheiros, and S. W. Kim. 2015. Effects of feed grade L-methionine on intestinal redox status, intestinal development, and growth performance of young chickens compared with conventional DL-methionine. Journal of Animal Science 93(6):2977-2986.

Zelenka, J., J. Heger, V. Machander, M. Wiltafsky, and M. Lešták. 2013. Bioavailability of liquid methionine hydroxy analogue-free acid relative to DL-methionine in broilers. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis 61(5):1513-1520.

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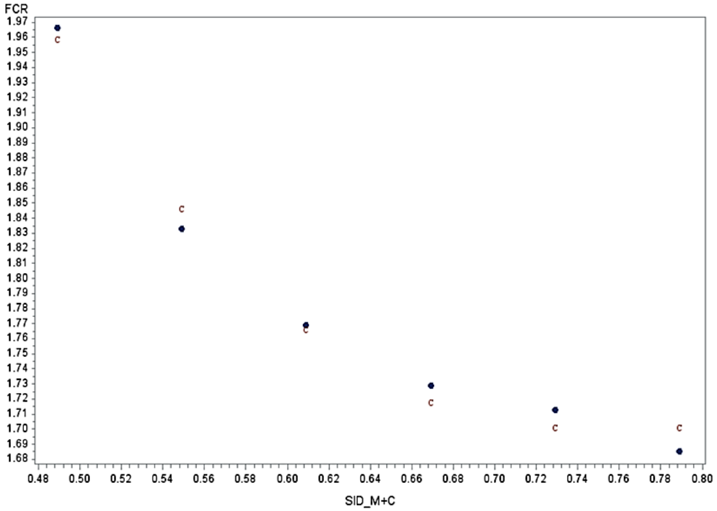
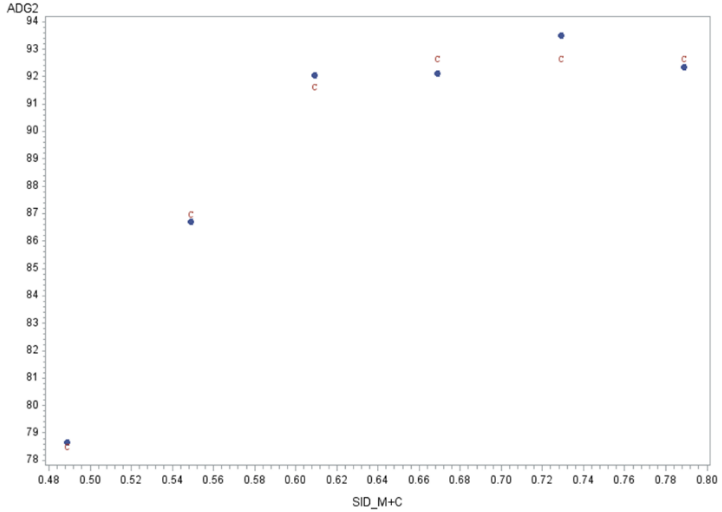
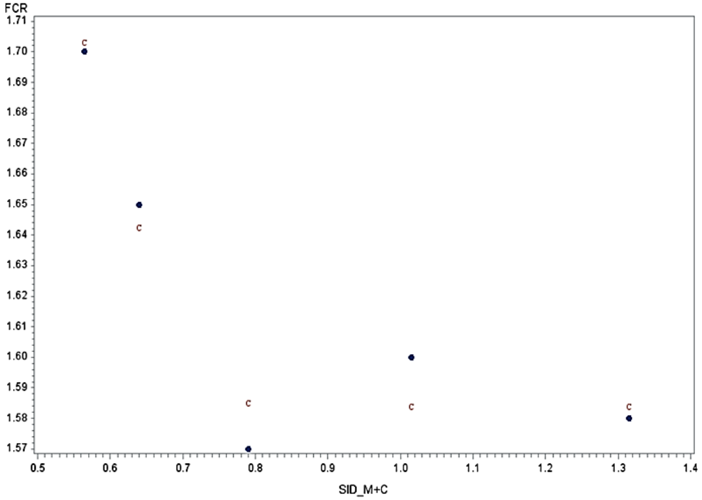
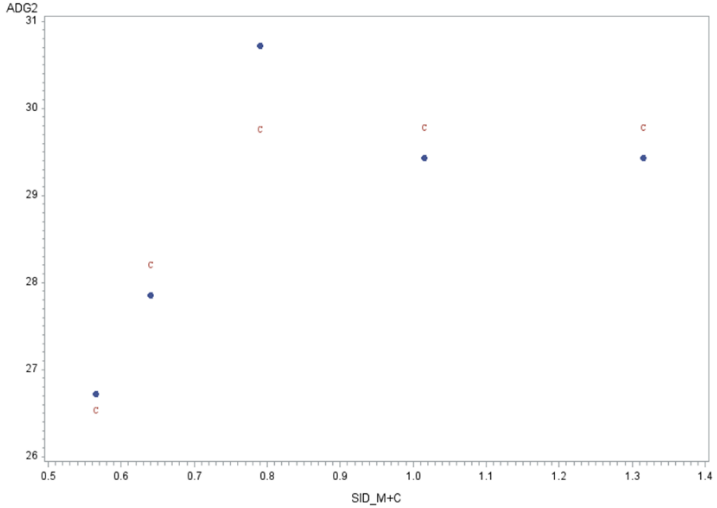
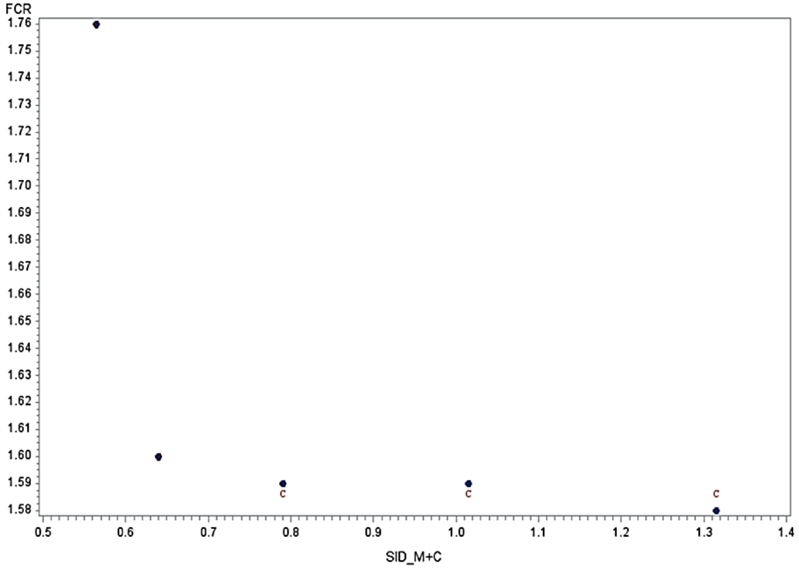
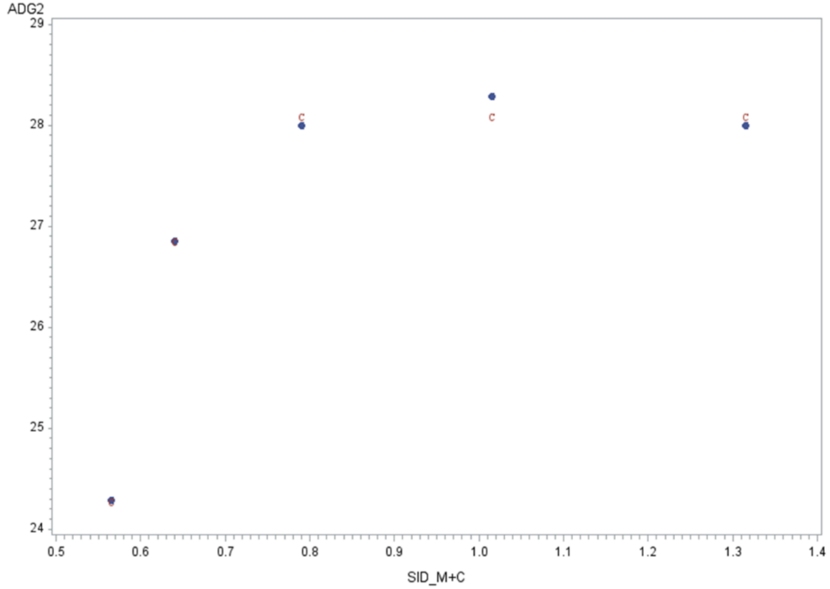
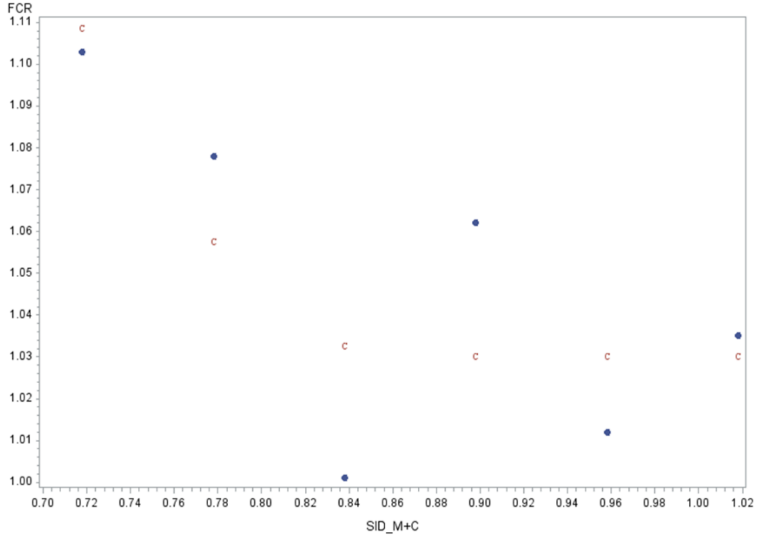
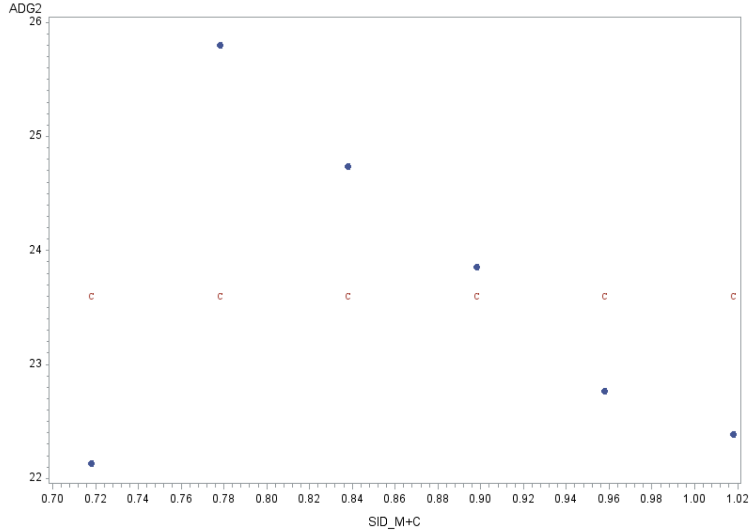
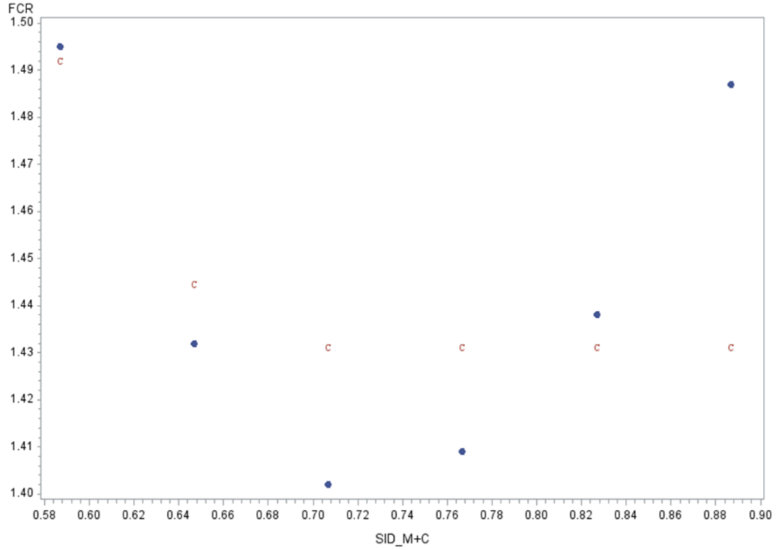
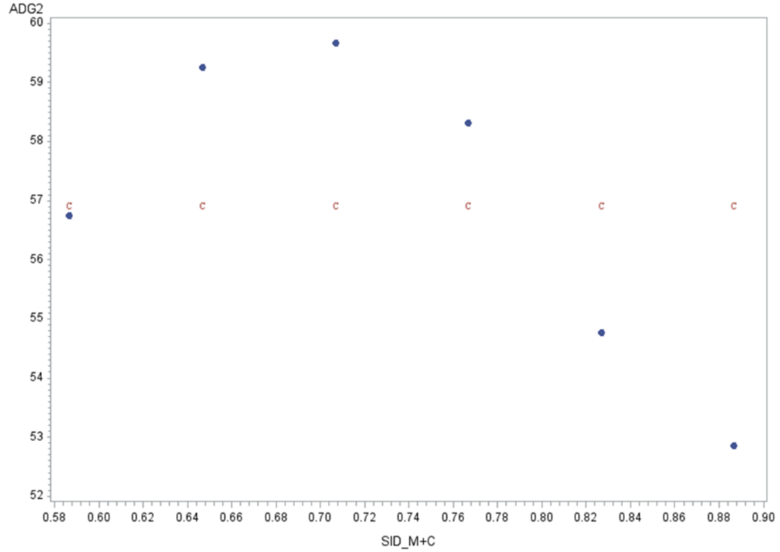
Veldkamp, T., J.W. van Riel, R.A. Dekker, S. Khalaji, V. Khaksar, H. Hashemipour, M.M. van Krimpen, and M.C. Blok. 2016. Estimating requirement values for apparent faecal digestible and standardised ileal digestible methionine+cysteine in broilers by a meta-analysis approach.

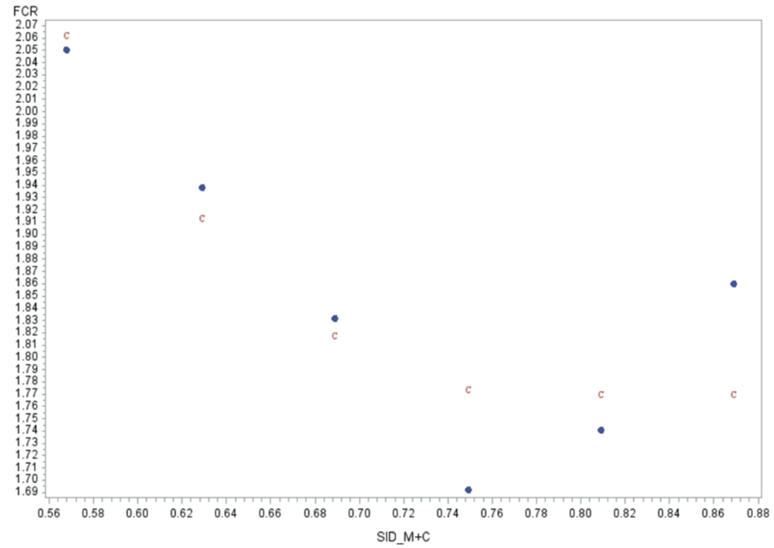
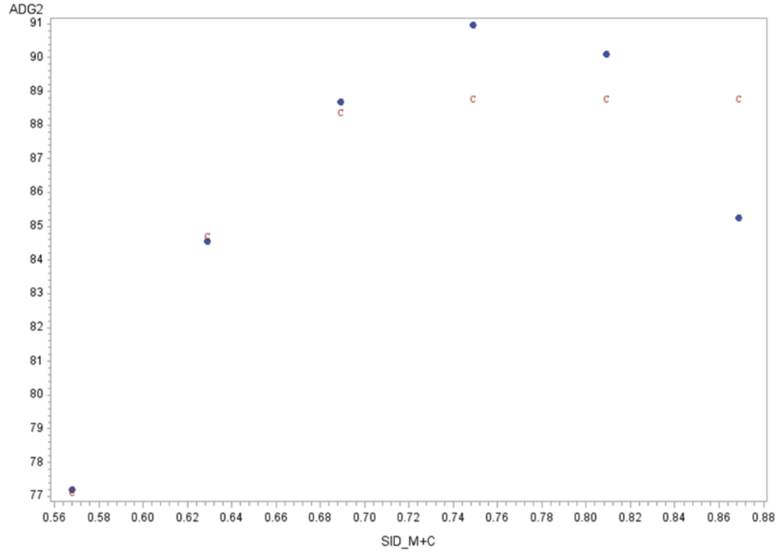
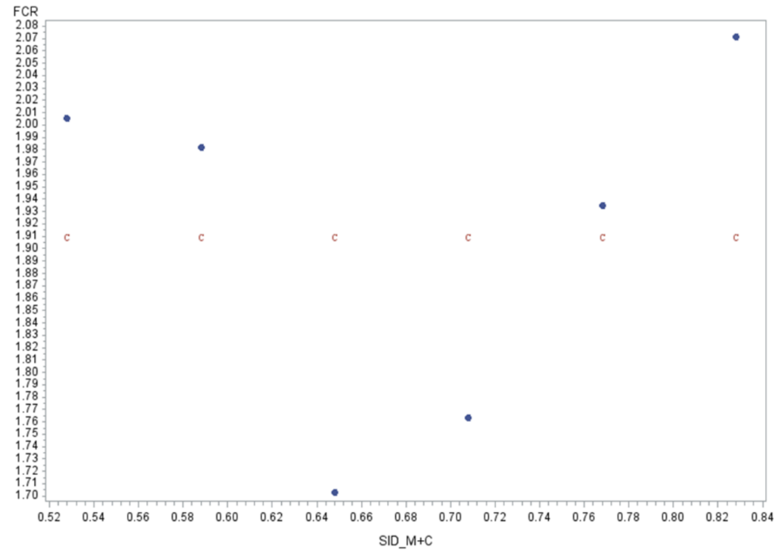
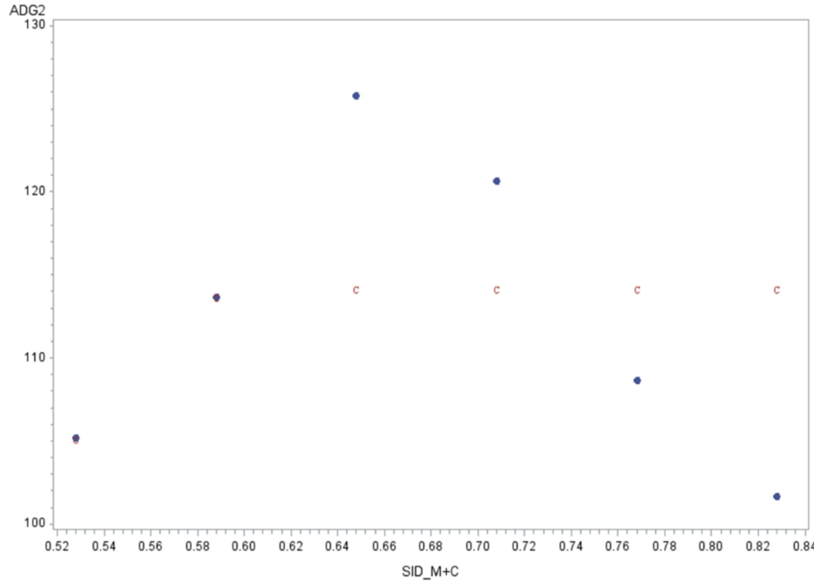
Appendix A. Relationship between dietary SID-M+C supply and performance parameters FCR and BWG for the various titration trials.

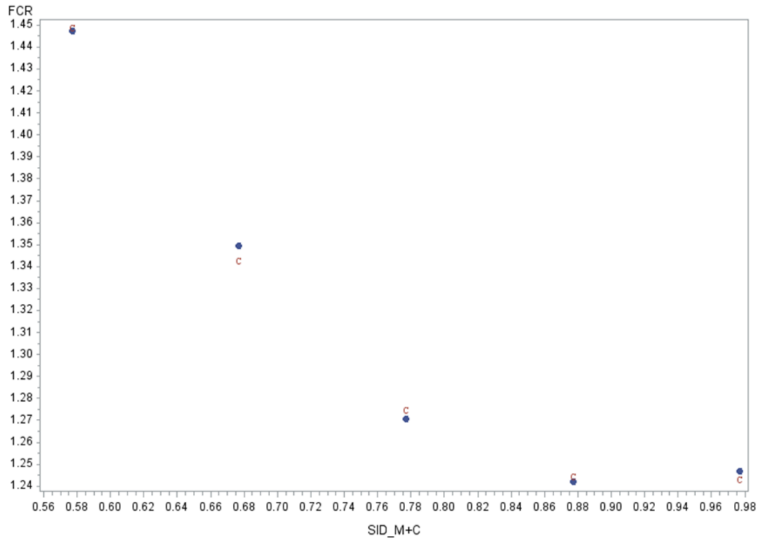
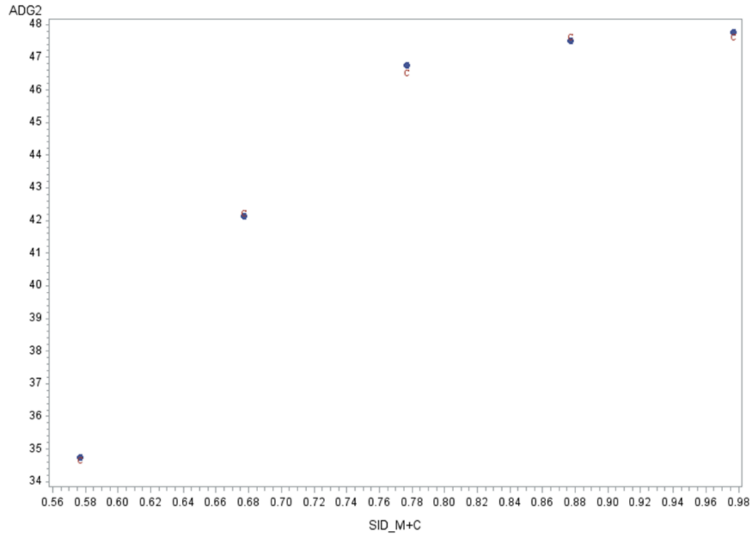
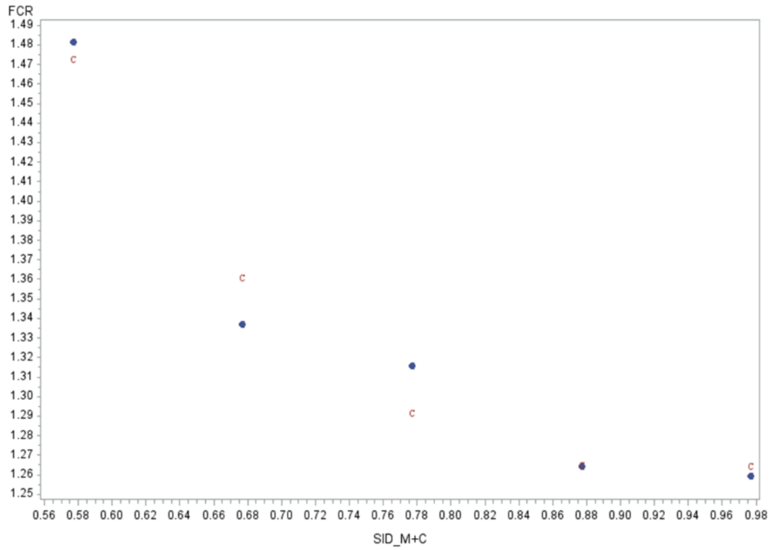
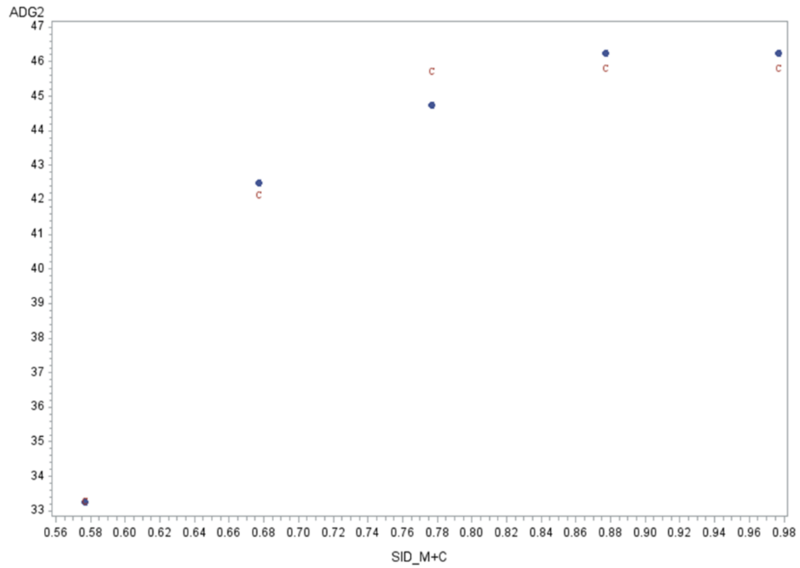
On the x-axis of the Figures the dietary M+C concentration (%) is given and on the y-axis of the Figures the FCR (left hand Figures) and BWG (right hand figures) are given. The closed circles are the observed values and the 'c' symbols are the fitted values.

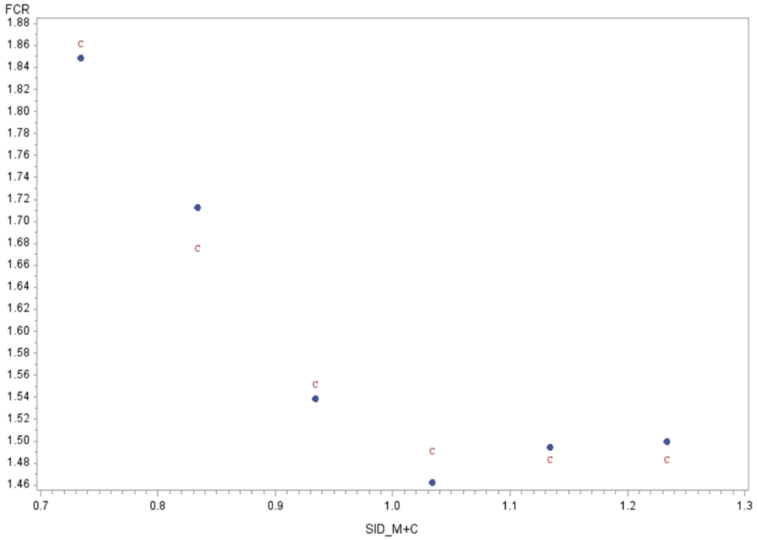
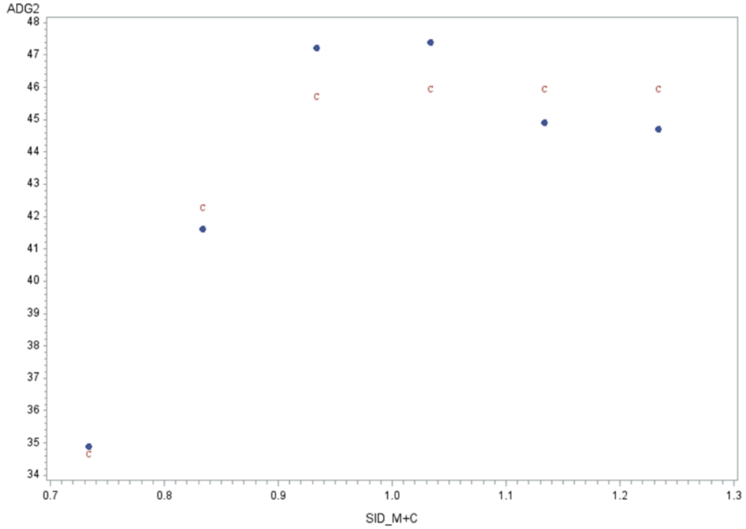
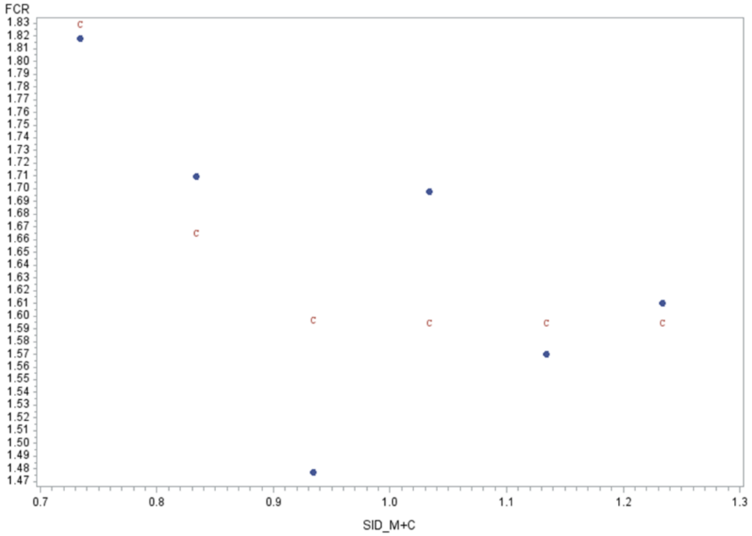
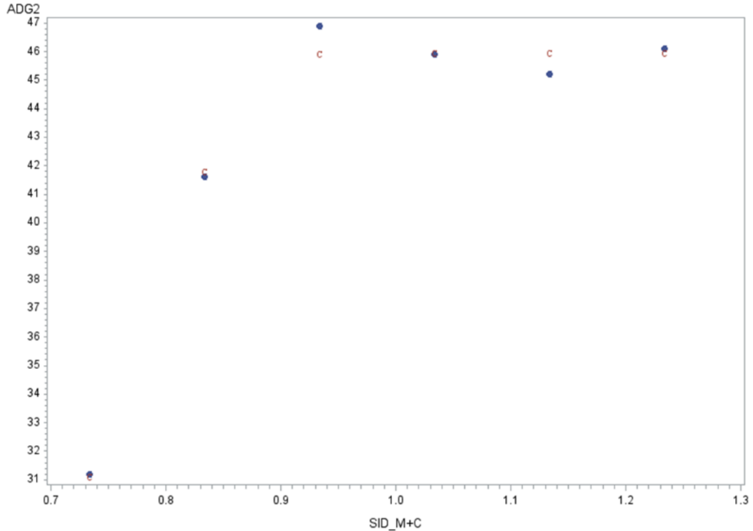
Trial	FCR	BWG
1. Mack et al. (1999) Optimal SID-M+C FCR (%): 0.730 Optimal SID-M+C BWG (%): 0.653		

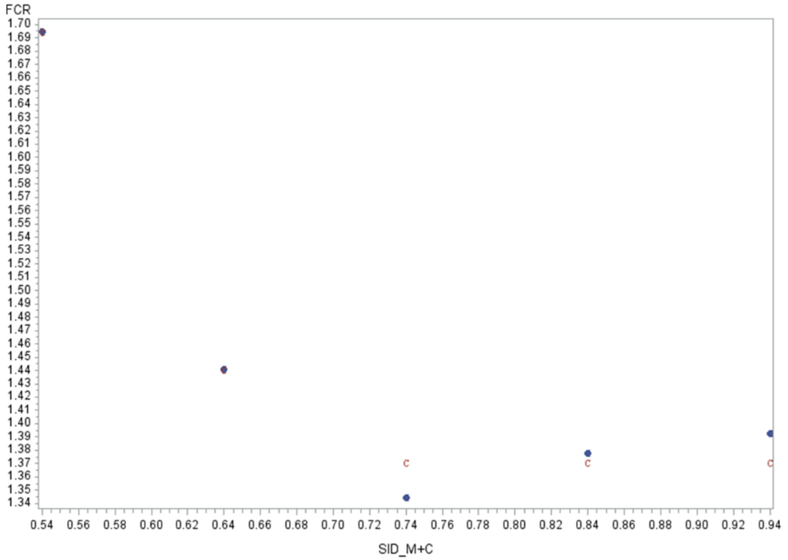
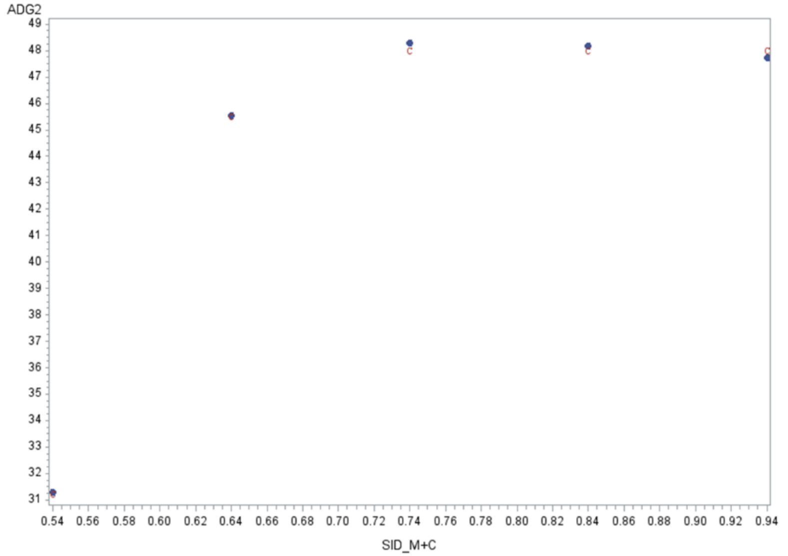
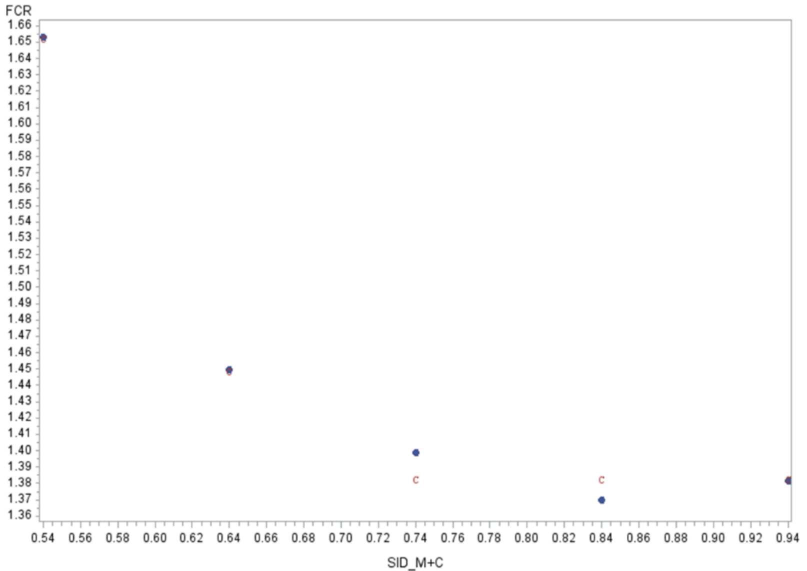
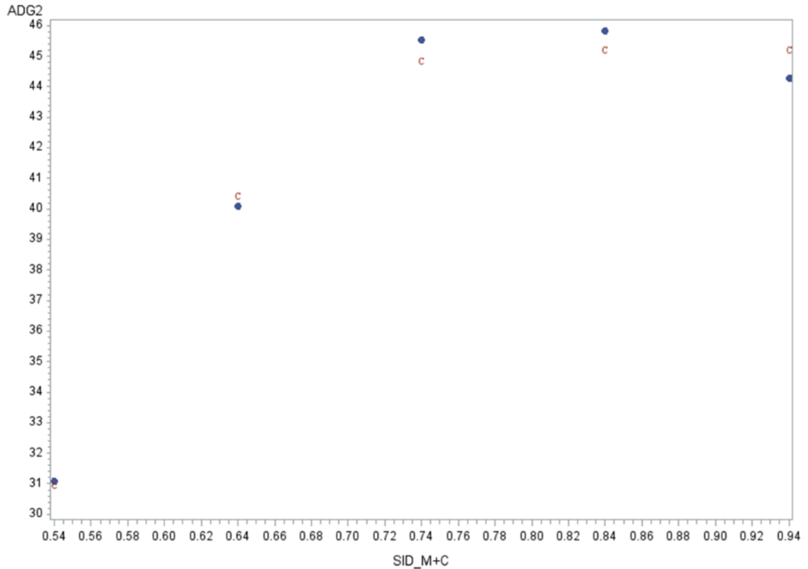
2. Chamruspollert et al. (2002) Trial 1 Optimal SID-M+C FCR (%): 0.817 Optimal SID-M+C BWG (%): 0.812		
3. Chamruspollert et al. (2002) Trial 2 Optimal SID-M+C FCR (%): 0.669 Optimal SID-M+C BWG (%): 0.740		

4. Castro Goulart et al. (2001) Trial 1 Optimal SID-M+C FCR (%): 0.865 Optimal SID-M+C BWG (%): Could not be estimated		
5. Castro Goulart et al. (2001) Trial 2 Optimal SID-M+C FCR (%): 0.700 (not a reliable estimate) Optimal SID-M+C BWG (%): Could not be estimated		

6. Castro Goulart et al. (2001) Trial 3 Optimal SID-M+C FCR (%): 0.772 Optimal SID-M+C BWG (%): 0.717		
7. Castro Goulart et al. (2001) Trial 4 Optimal SID-M+C FCR (%): Could not be estimated Optimal SID-M+C BWG (%): 0.607		

8. Lumpkins et al. (2007) Trial 1 Optimal SID-M+C FCR (%): 0.906 Optimal SID-M+C BWG (%): 0.858		
9. Lumpkins et al. (2007) Trial 2 Optimal SID-M+C FCR (%): 0.890 Optimal SID-M+C BWG (%): 0.795		

10. Lumpkins et al. (2007) Trial 3 Optimal SID-M+C FCR (%): 1.082 Optimal SID-M+C BWG (%): 0.967		
11. Lumpkins et al. (2007) Trial 4 Optimal SID-M+C FCR (%): 0.956 Optimal SID-M+C BWG (%): 0.947		

12. Lumpkins et al. (2007) Trial 5 Optimal SID-M+C FCR (%): 0.726 Optimal SID-M+C BWG (%): 0.703		
13. Lumpkins et al. (2007) Trial 6 Optimal SID-M+C FCR (%): 0.738 Optimal SID-M+C BWG (%): 0.778		

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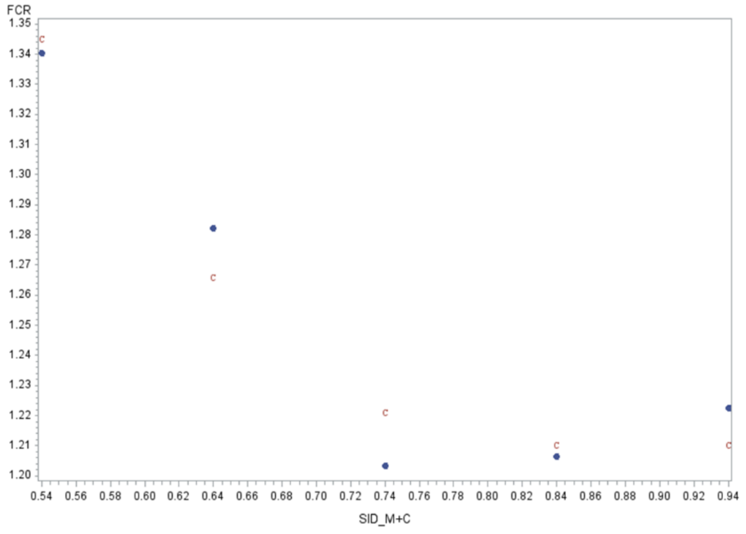
<td>14.
Lumpkins et al. (2007)
Trial 7

Optimal SID-M+C FCR (%):
0.819

Optimal SID-M+C BWG (%):
0.695</td>
<td>
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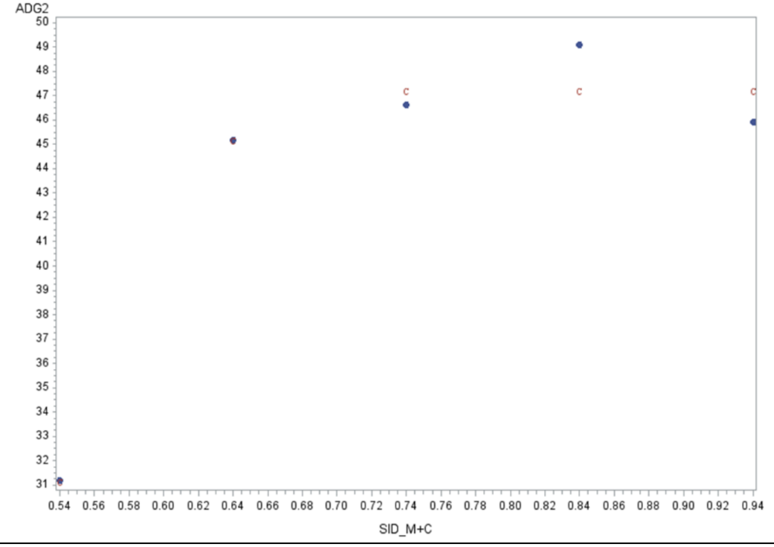
<td>
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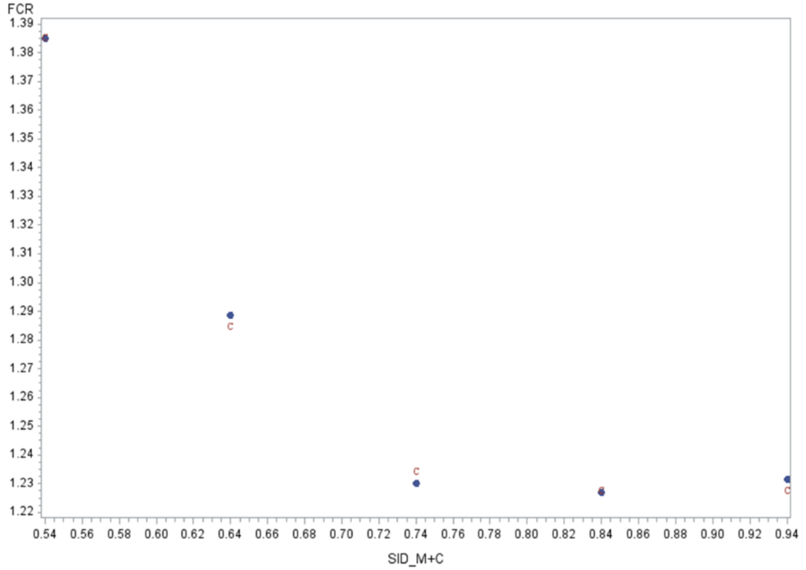
<td>15.
Lumpkins et al. (2007)
Trial 8

Optimal SID-M+C FCR (%):
0.792

Optimal SID-M+C BWG (%):
0.713</td>
<td>
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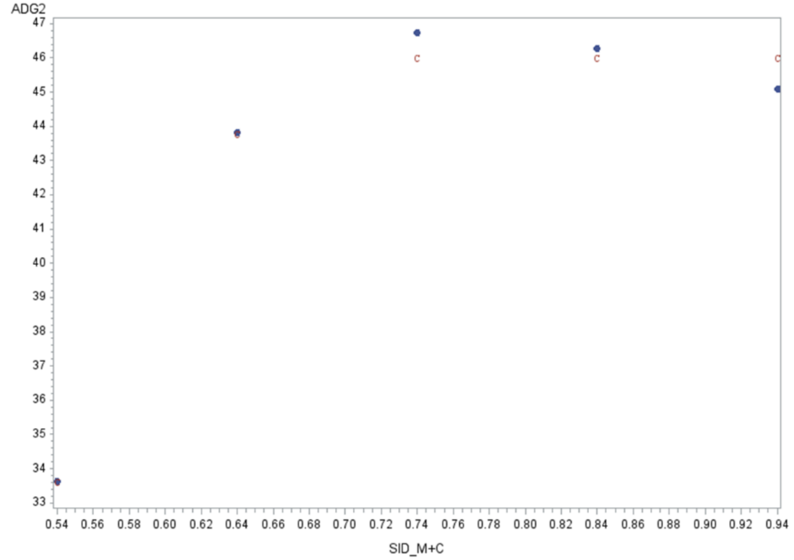
<td>
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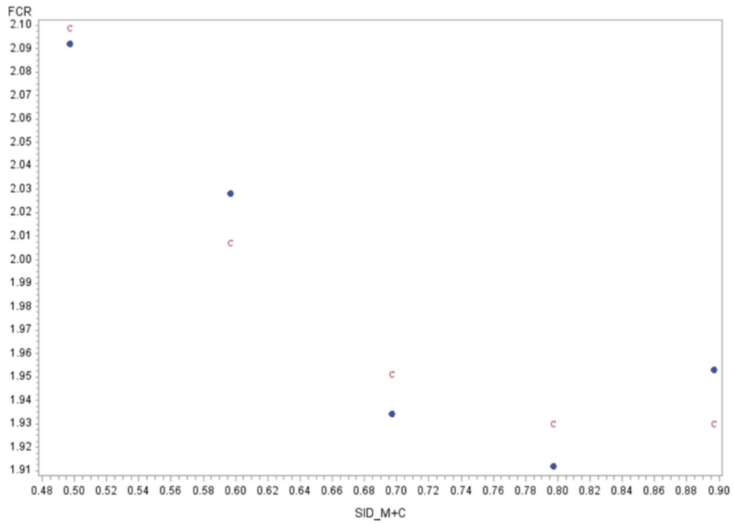
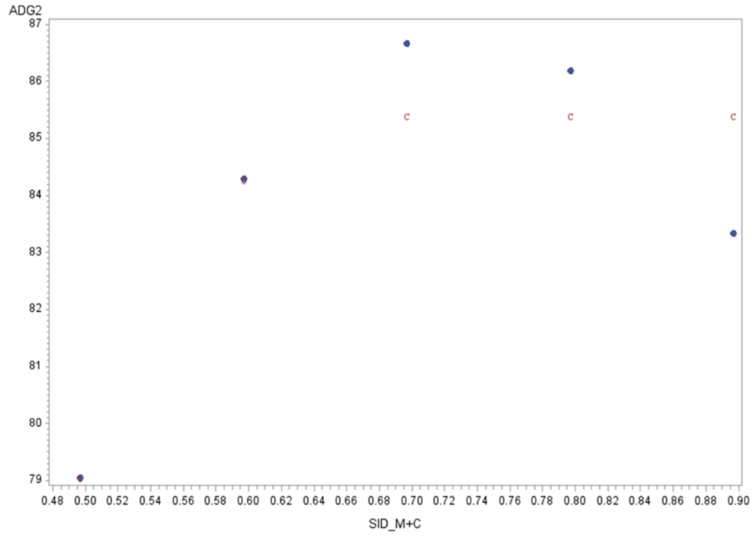
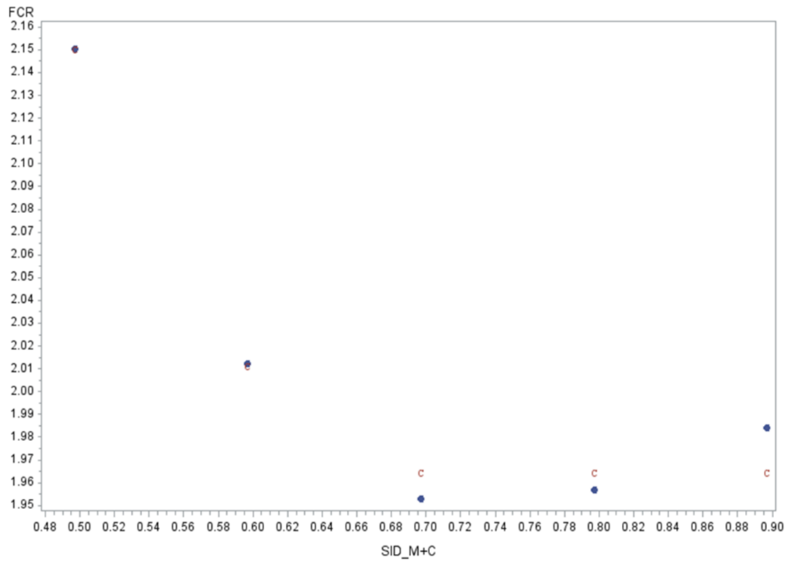
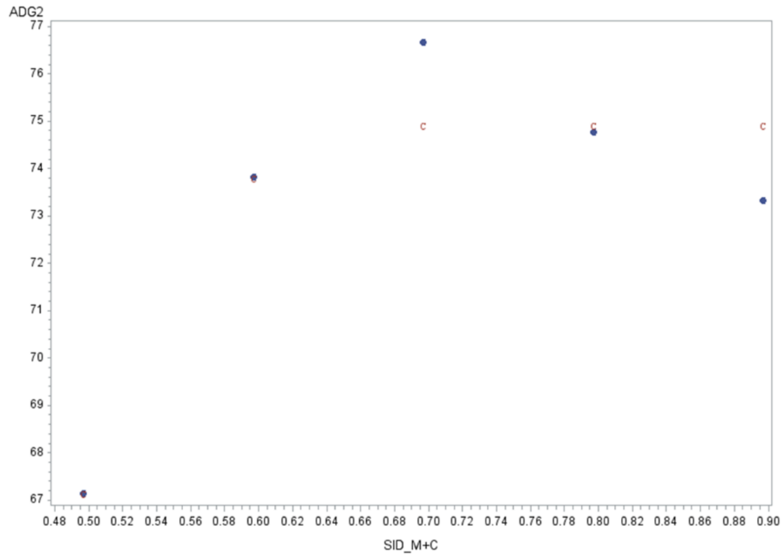
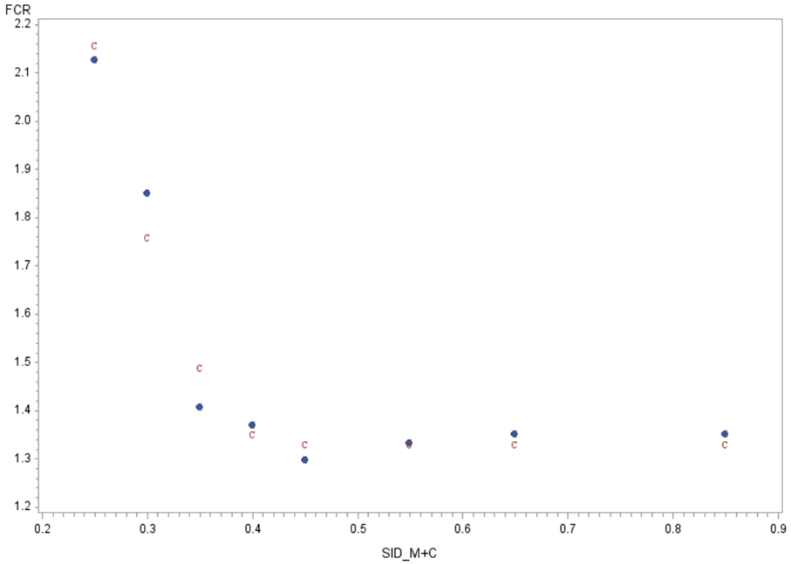
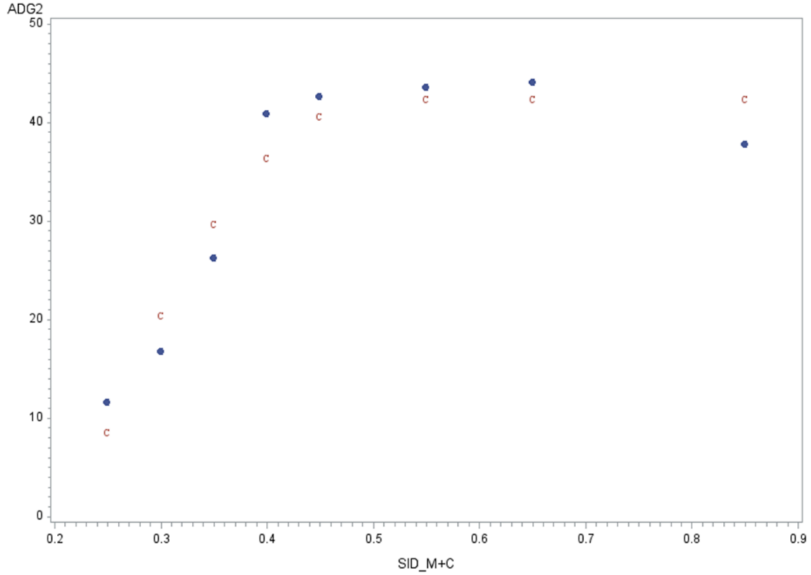
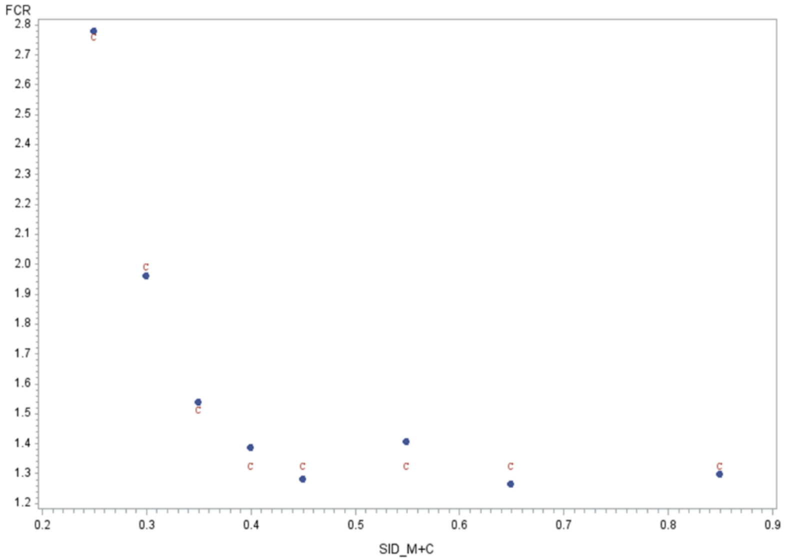
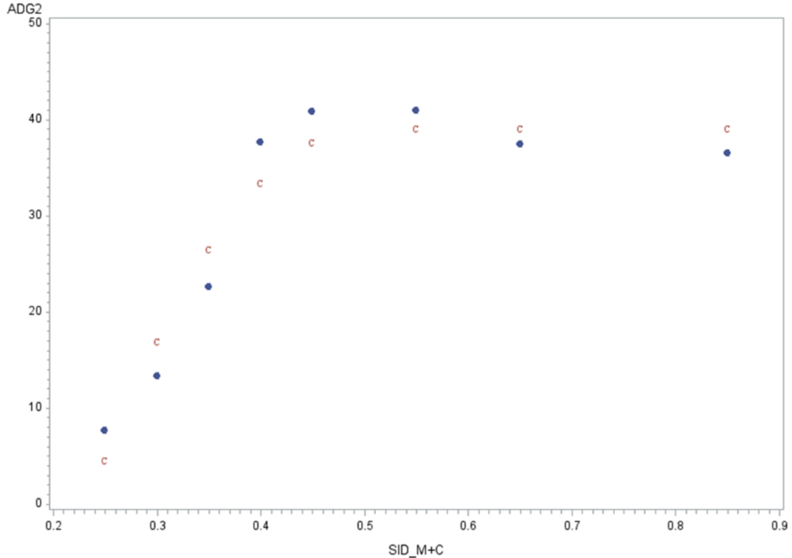
16. Lumpkins et al. (2007) Trial 9 Optimal SID-M+C FCR (%): 0.806 Optimal SID-M+C BWG (%): 0.669		
17. Lumpkins et al. (2007) Trial 10 Optimal SID-M+C FCR (%): 0.698 Optimal SID-M+C BWG (%): 0.658		

18. Fatufe en Rodehutscord (2005) Trial 1 Optimal SID-M+C FCR (%): 0.428 Optimal SID-M+C BWG (%): 0.508		
19. Fatufe en Rodehutscord (2005) Trial 2 Optimal SID-M+C FCR (%): 0.406 Optimal SID-M+C BWG (%): 0.502		

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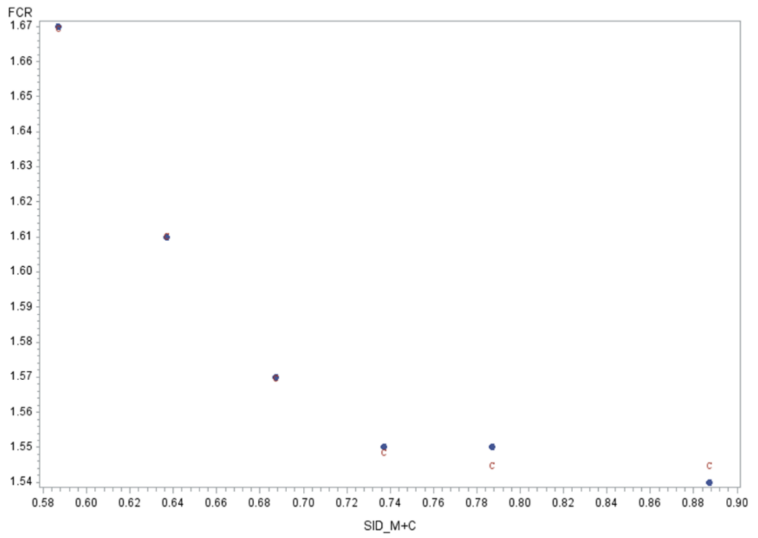
<td>20. Chamruspollert et al. (2004) Trial 1

Optimal SID-M+C FCR (%): 0.768

Optimal SID-M+C BWG (%): 0.732</td>
<td>
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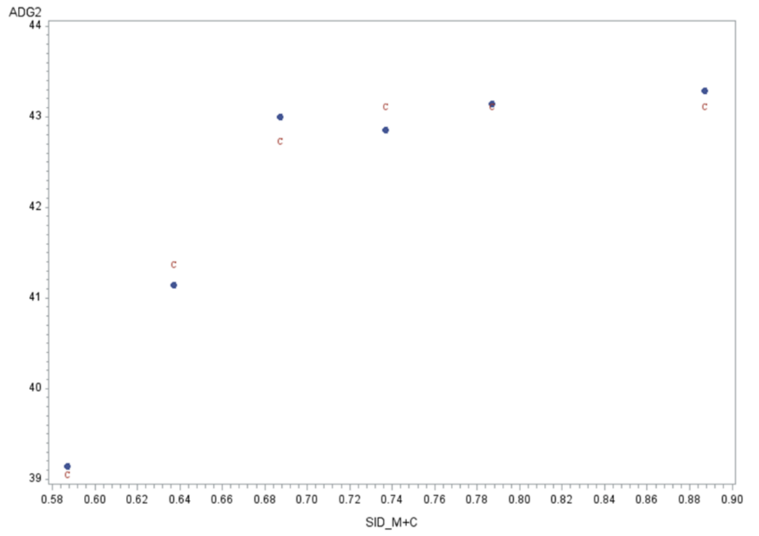
<td>
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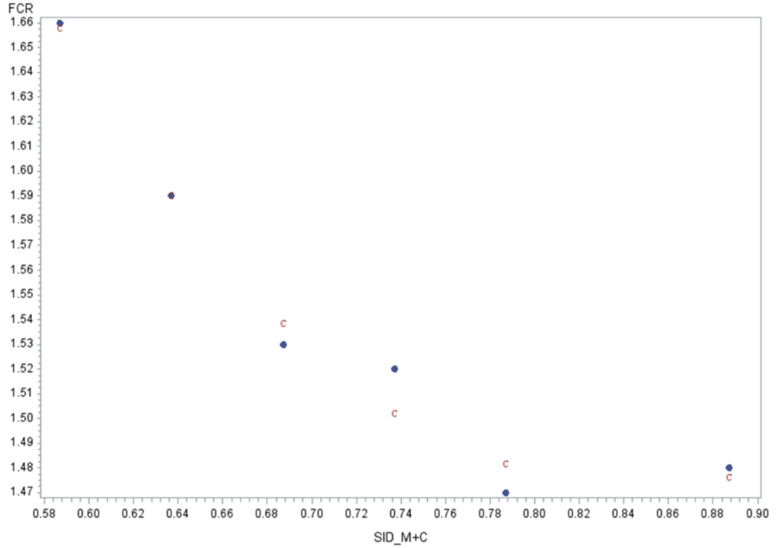
<td>21. Chamruspollert et al. (2004) Trial 2

Optimal SID-M+C FCR (%): 0.828

Optimal SID-M+C BWG (%): 0.707</td>
<td>
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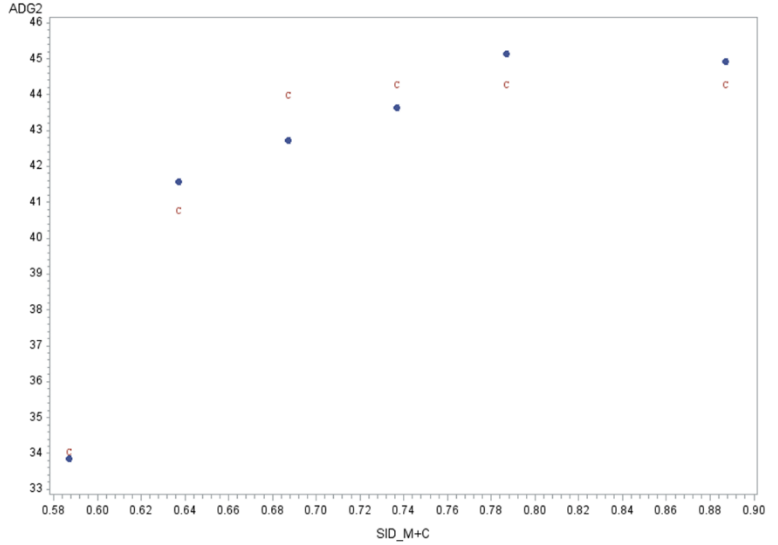
<td>
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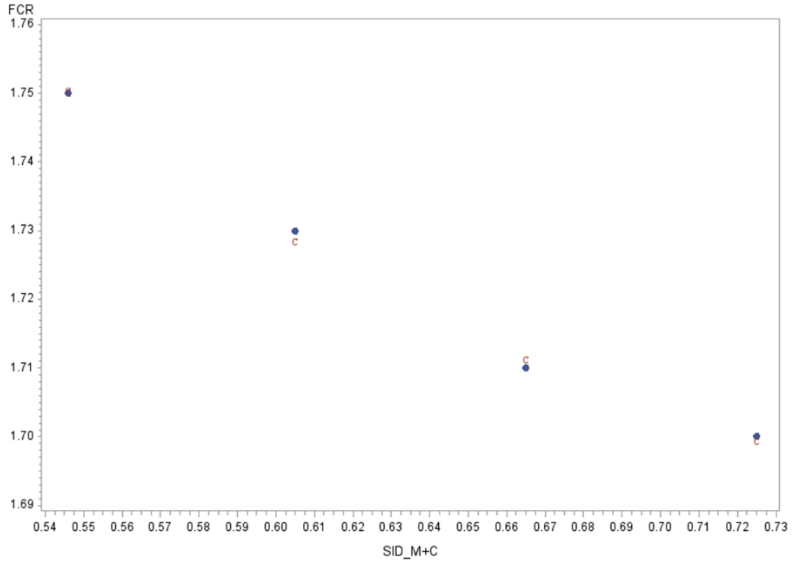
<td>22.
Kalinowski et al. (2003)
Trial 1

Optimal SID-M+C FCR (%): 0.832

Optimal SID-M+C BWG (%): 0.684</td>
<td>
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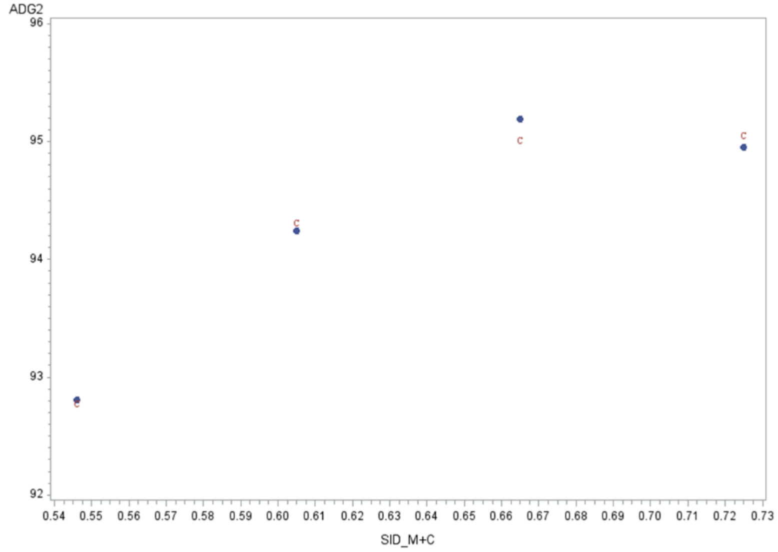
<td>
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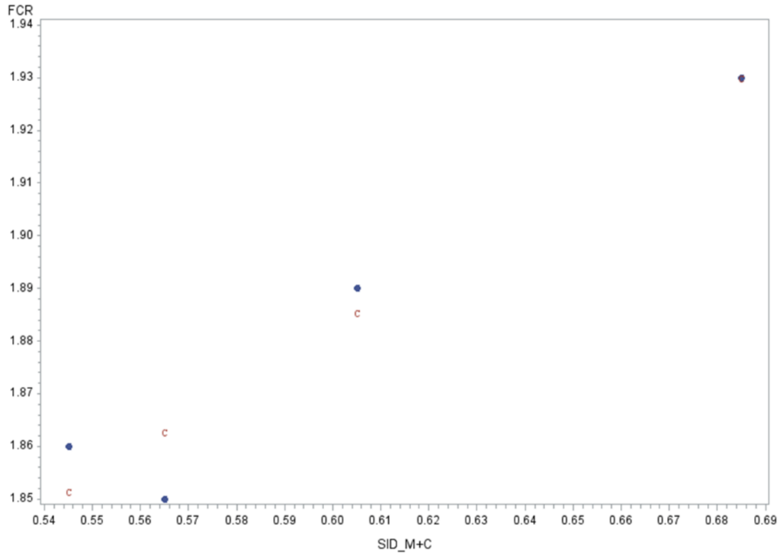
<td>24.
Kalinowski et al. (2003)
Trial 3

Optimal SID-M+C FCR (%): could not be estimated

Optimal SID-M+C BWG (%): Could not be estimated</td>
<td>
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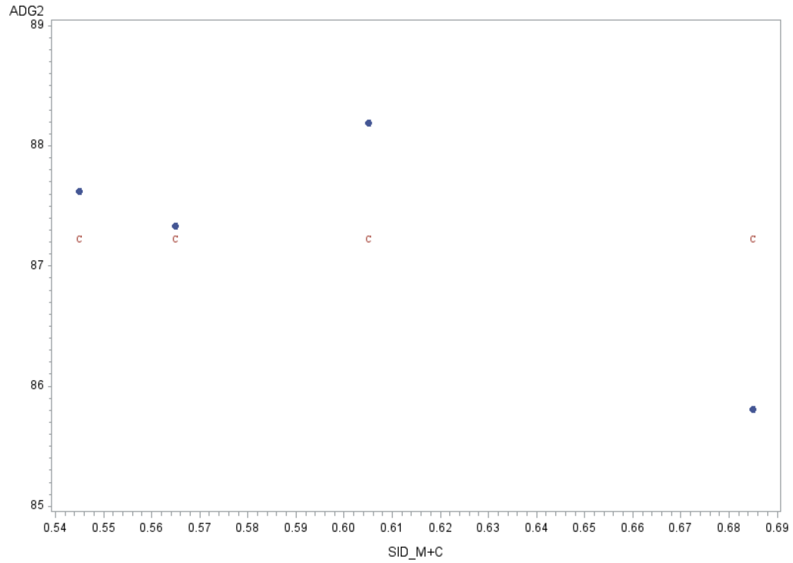
<td>
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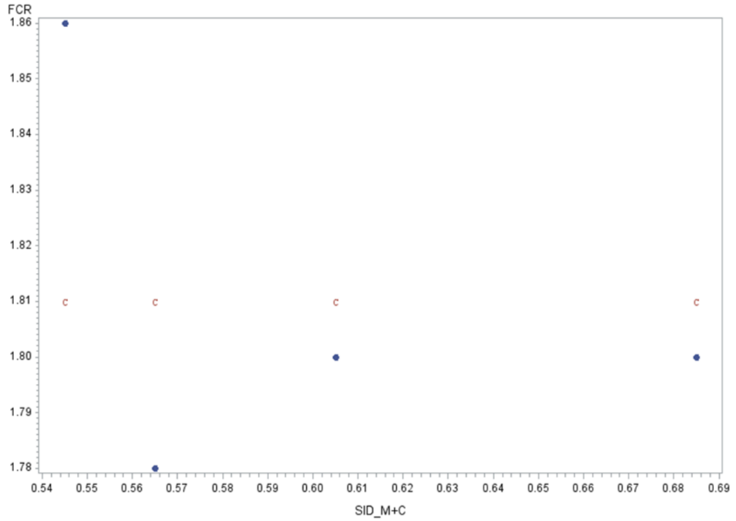
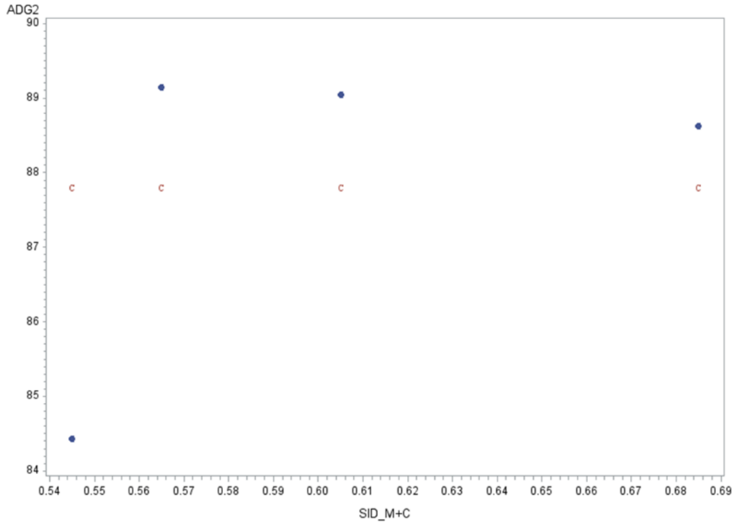
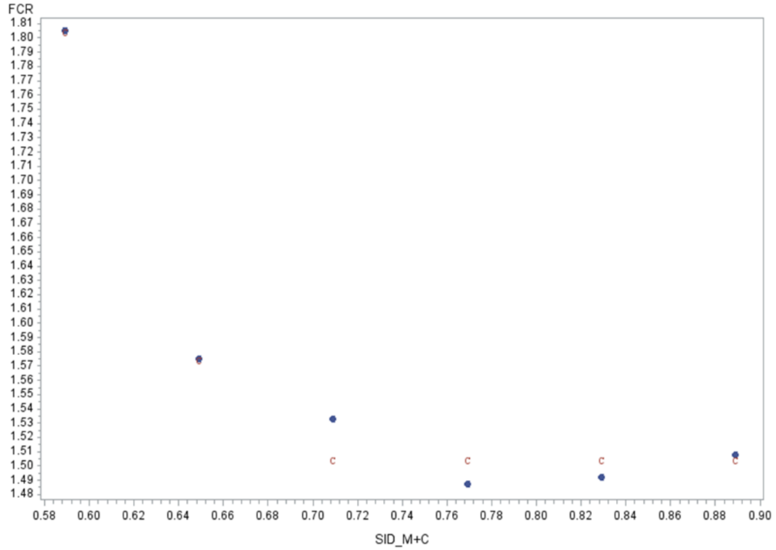
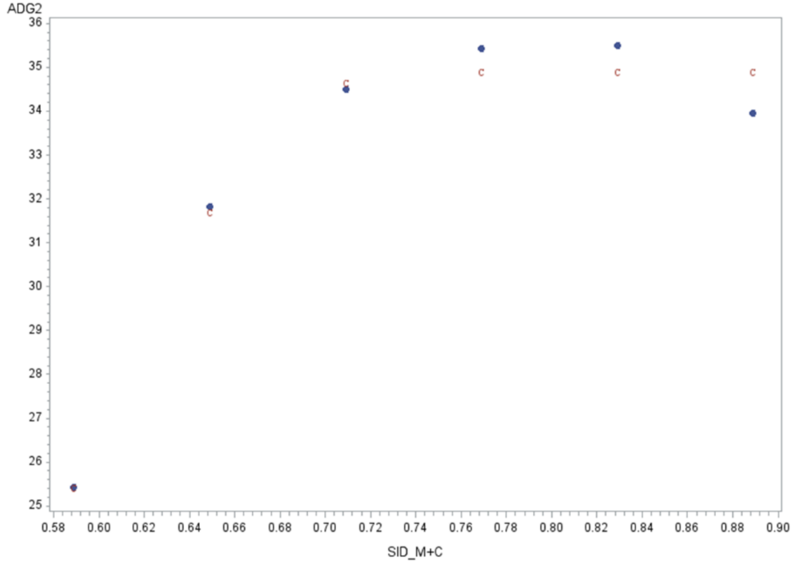
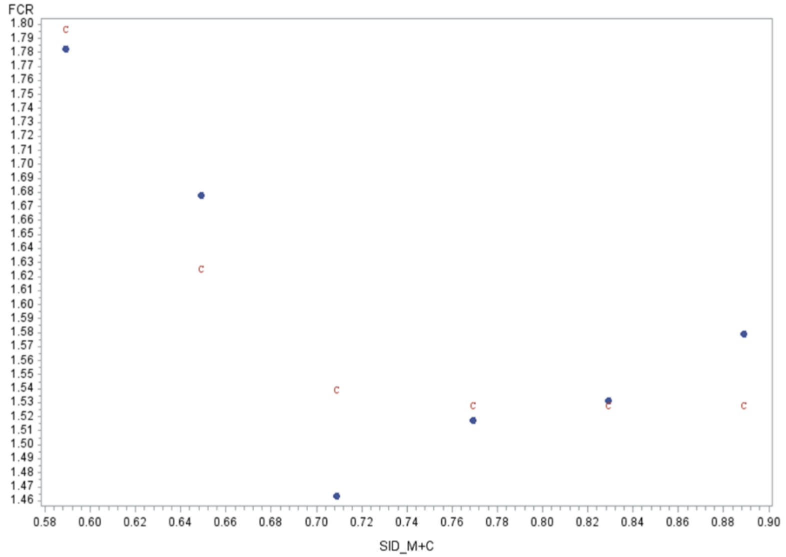
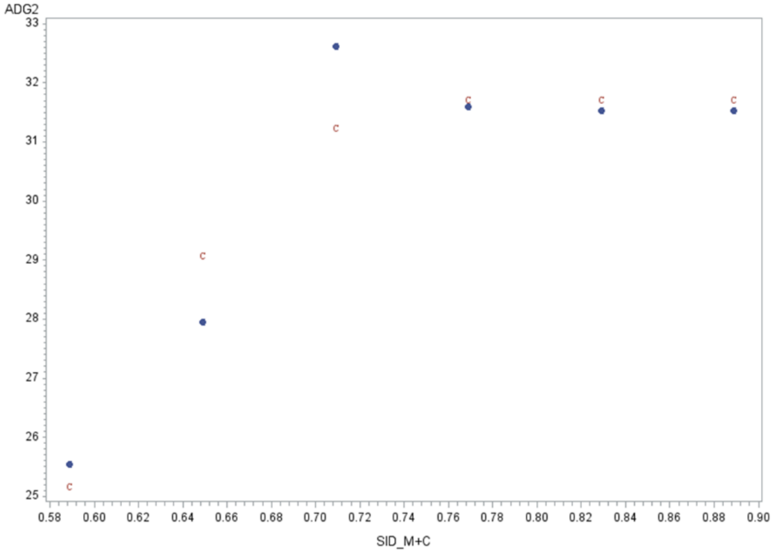
25. Kalinowski et al. (2003) Trial 4 Optimal SID-M+C FCR (%):Could not be estimated Optimal SID-M+C BWG (%): Could not be estimated		
26. Albino et al. (1999) Trial 1 Optimal SID-M+C FCR (%): 0.705 Optimal SID-M+C BWG (%): 0.733		

27.
Albino et al. (1999)
Trial 2

Optimal SID-M+C FCR (%): 0.740

Optimal SID-M+C BWG (%): 0.753

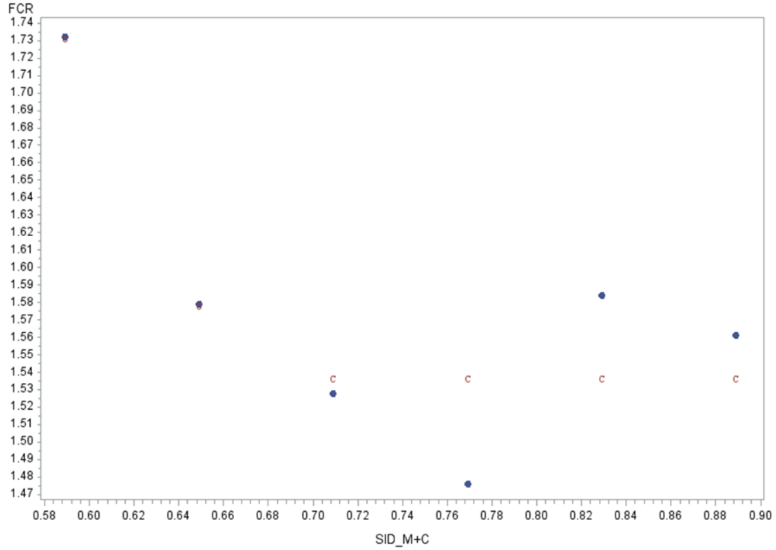


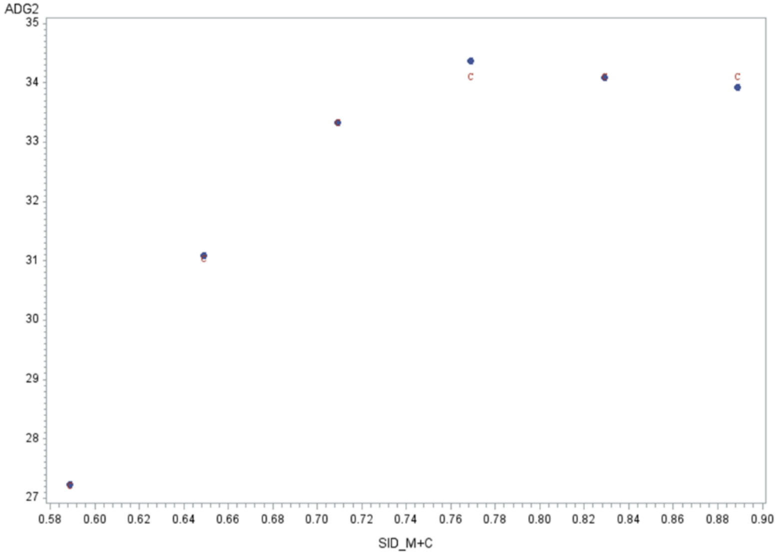


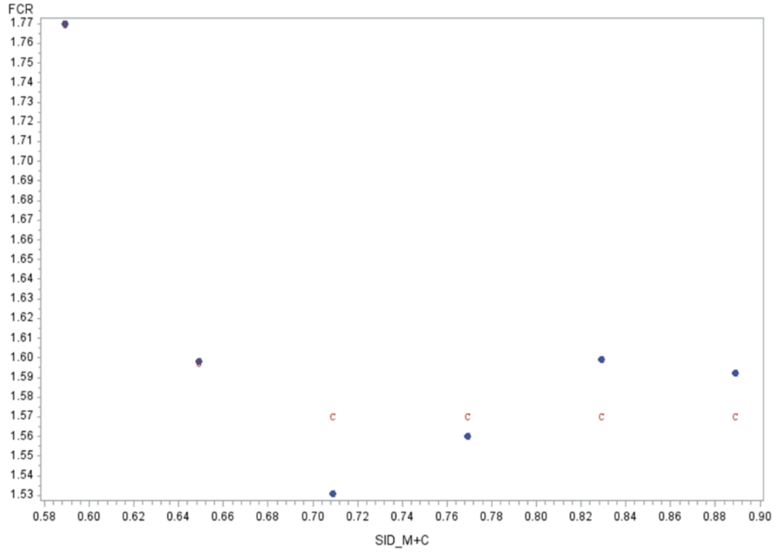
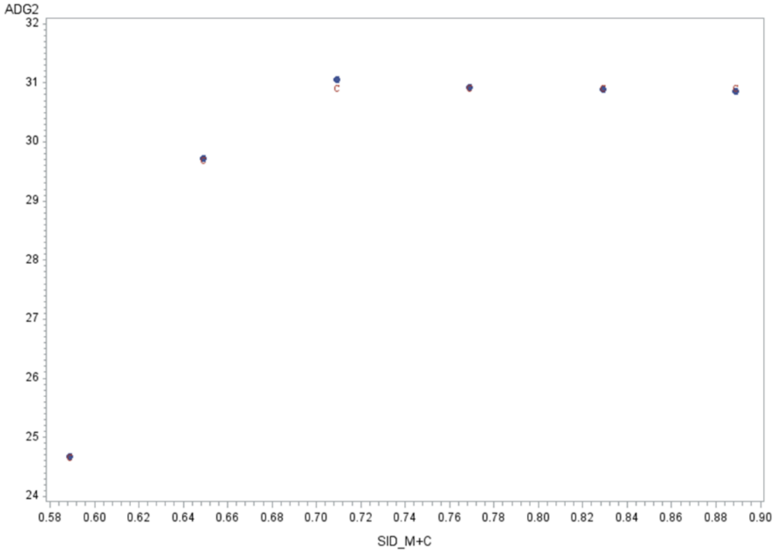
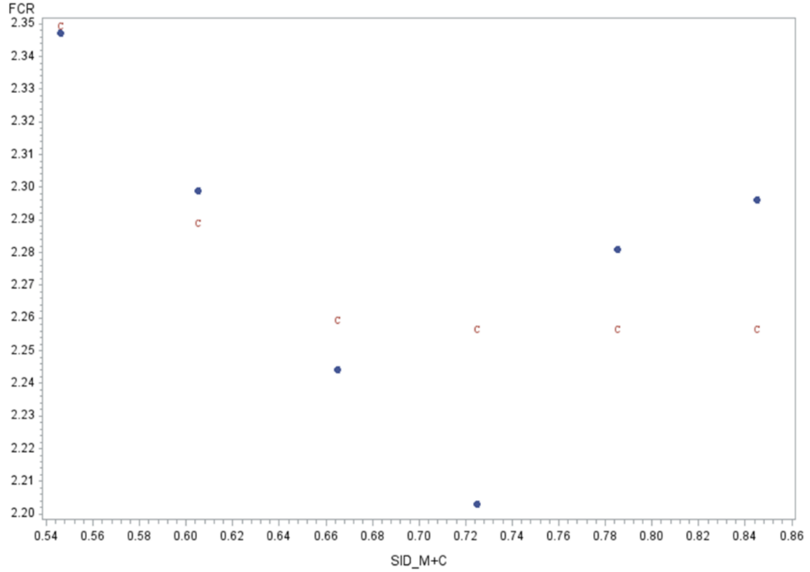
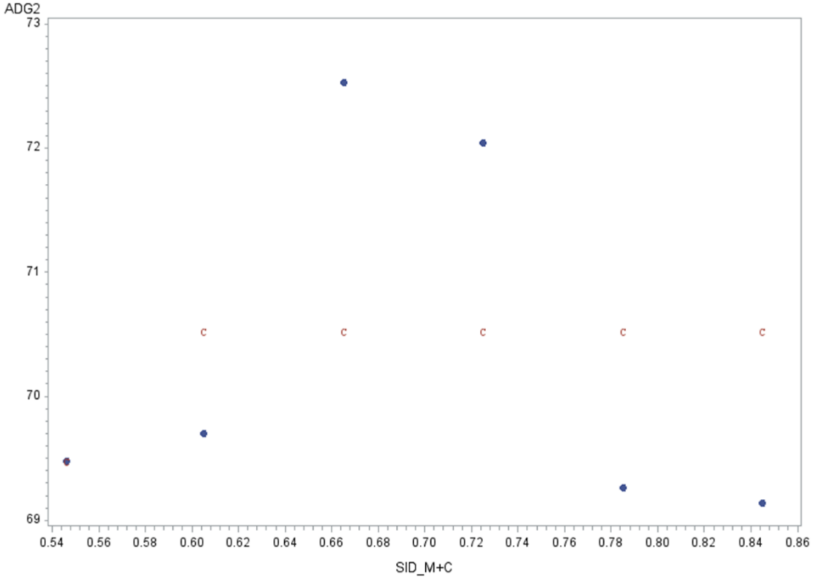
28.
Albino et al. (1999)
Trial 3

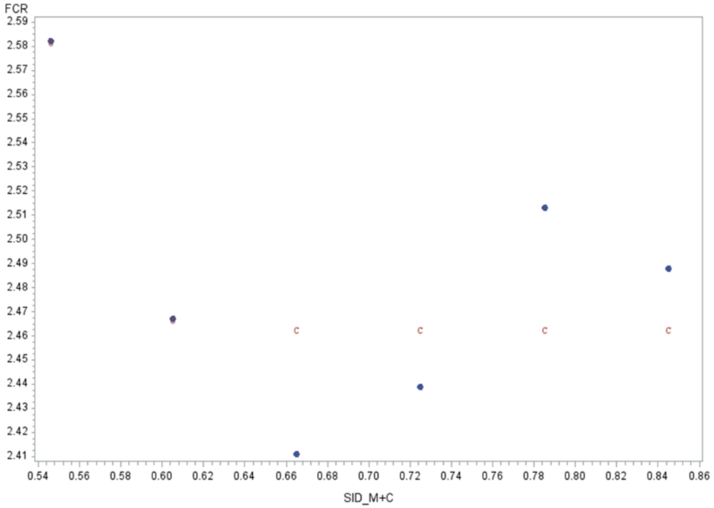
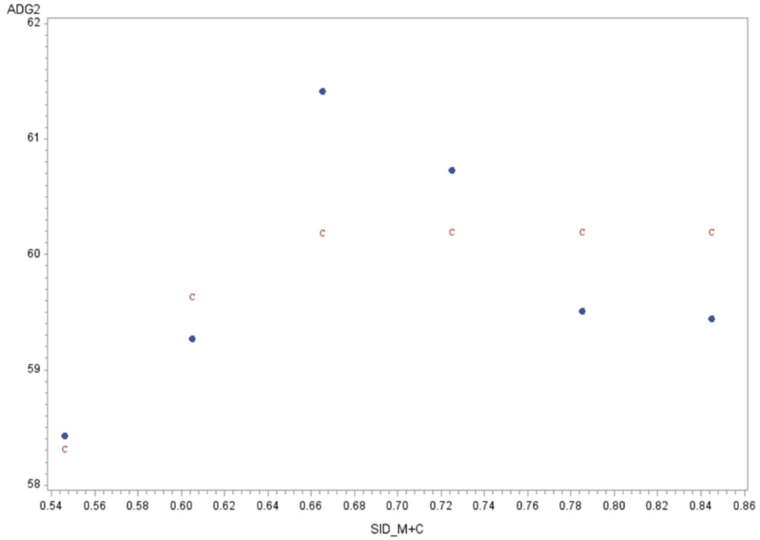
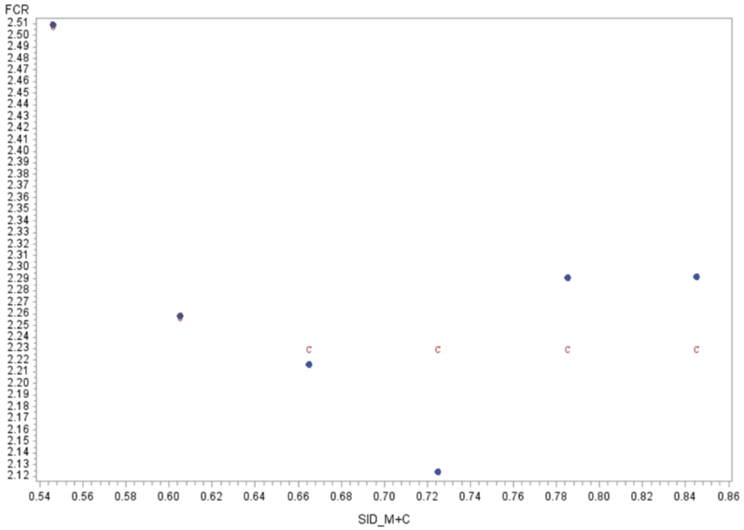
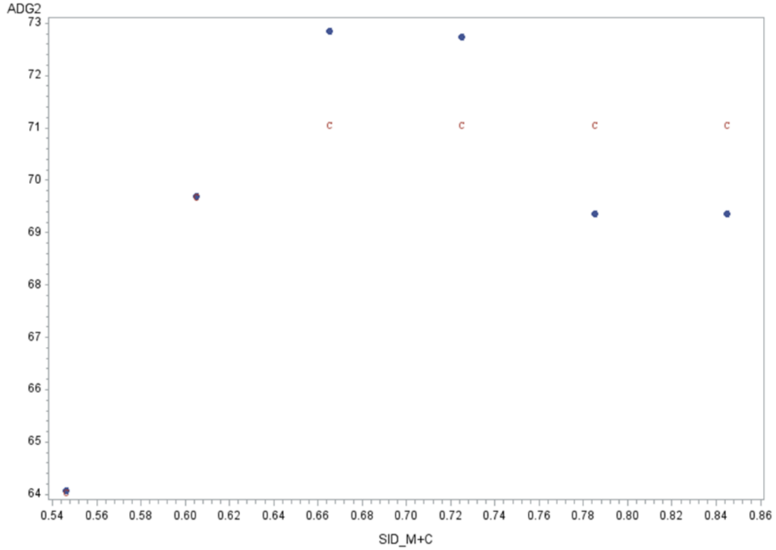
Optimal SID-M+C FCR (%): 0.701

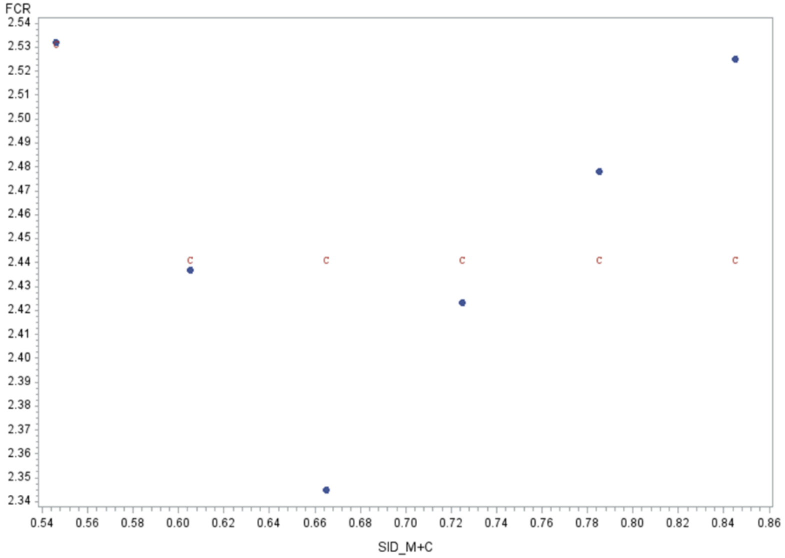
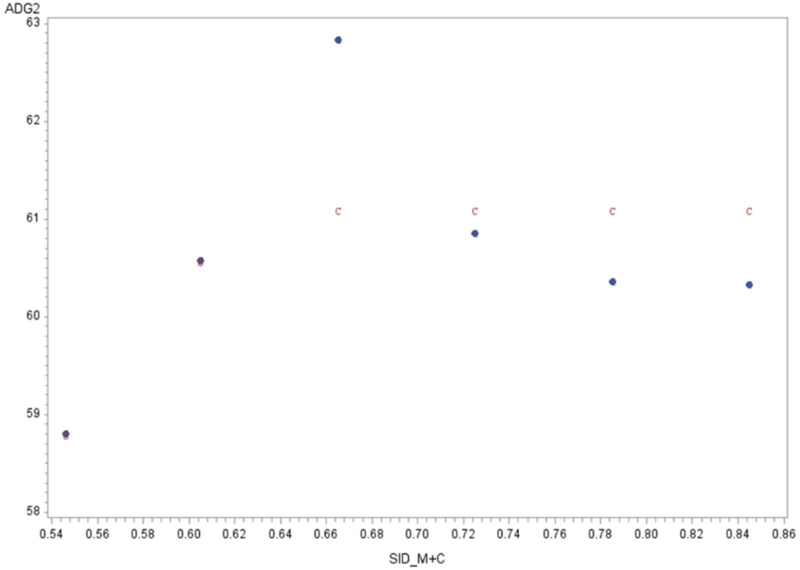
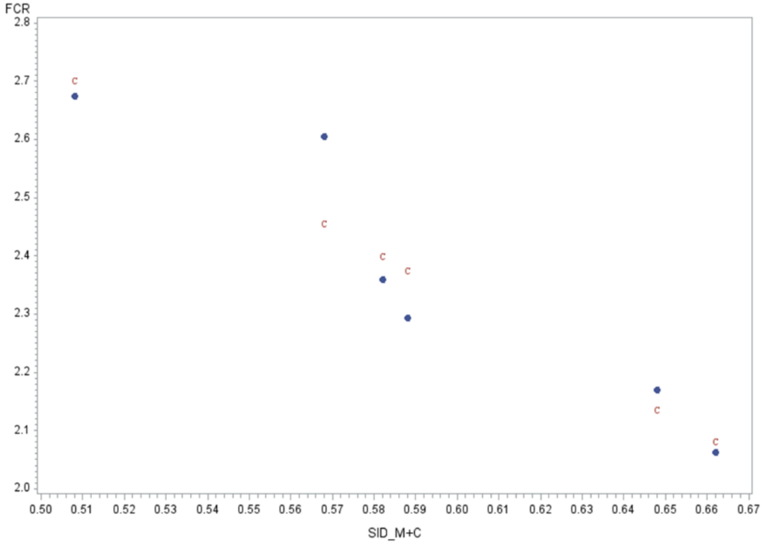
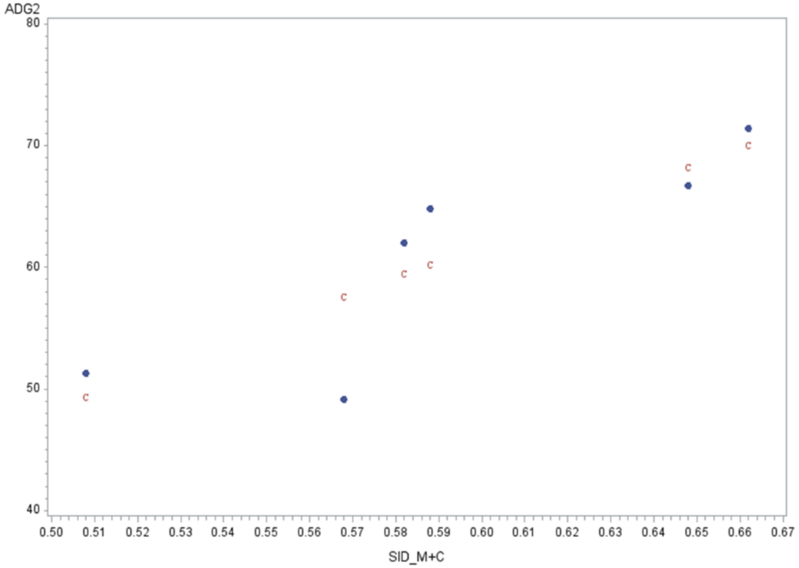
Optimal SID-M+C BWG (%): 0.769

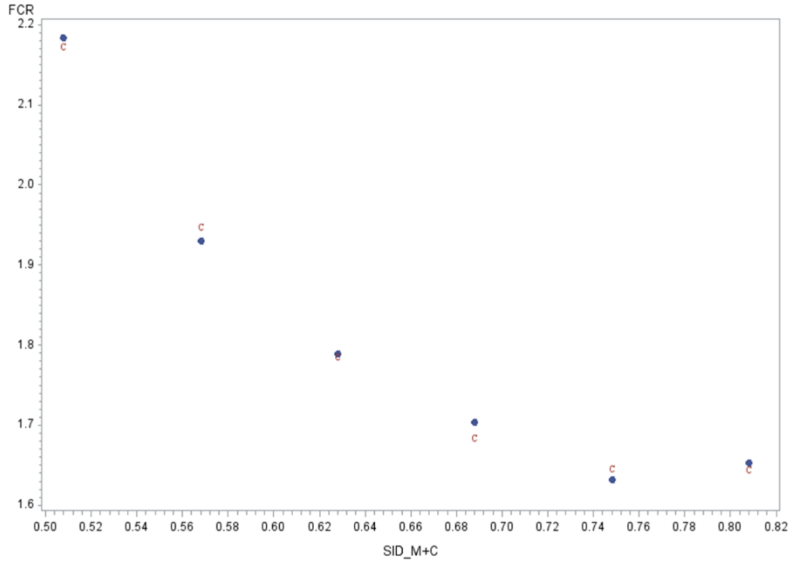
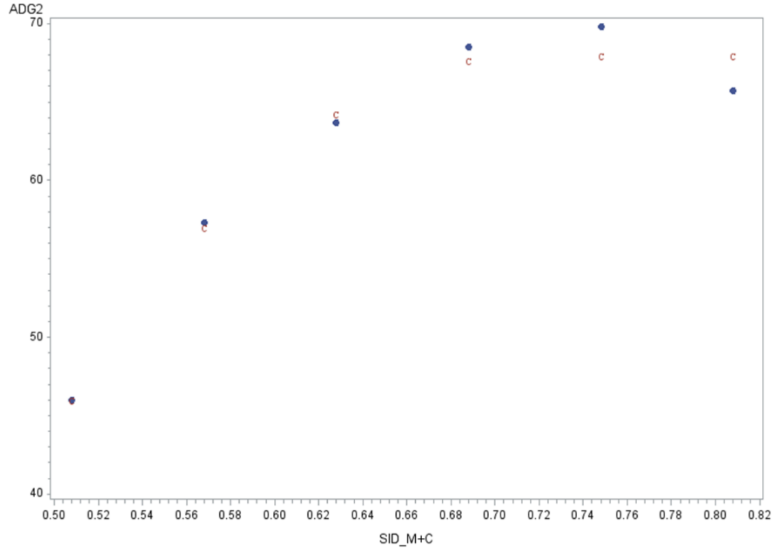
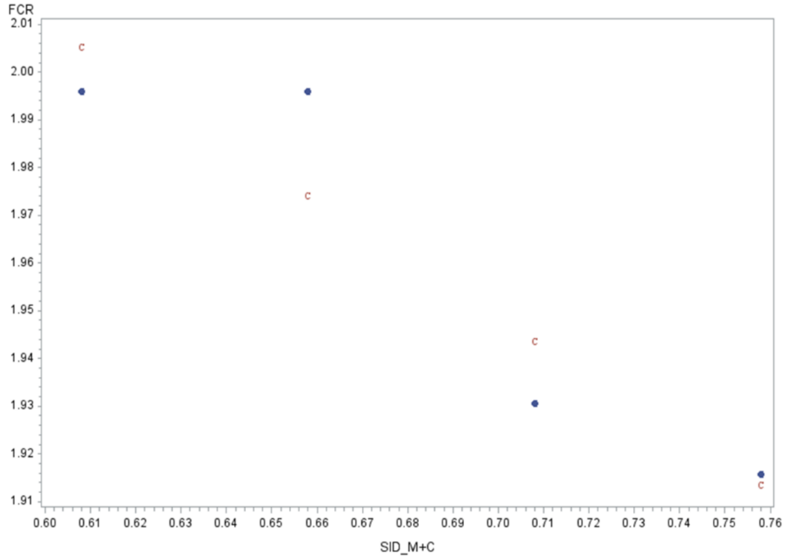
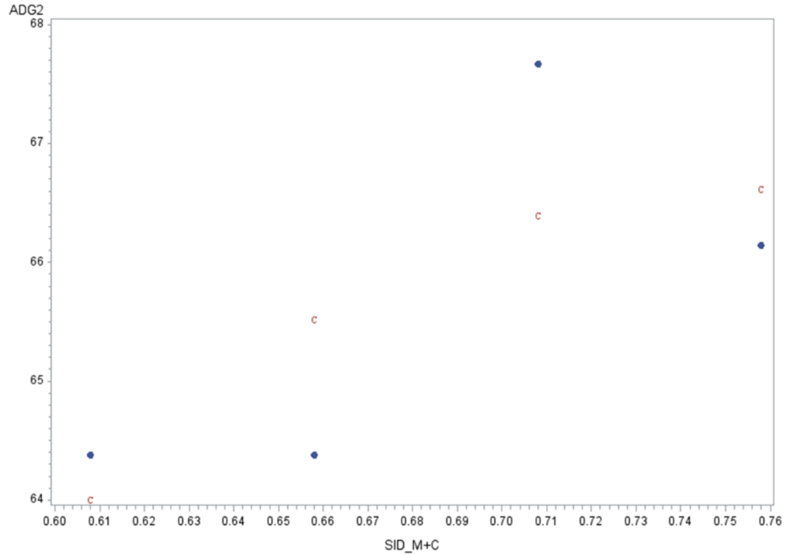




29. Albino et al. (1999) Trial 4 Optimal SID-M+C FCR (%): 0.684 Optimal SID-M+C BWG (%): 0.696		
30. Albino et al. (1999) Trial 5 Optimal SID-M+C FCR (%): 0.684 Optimal SID-M+C BWG (%): Could not be estimated		

31. Albino et al. (1999) Trial 6 Optimal SID-M+C FCR (%): 0.619 Optimal SID-M+C BWG (%): 0.676		
32. Albino et al. (1999) Trial 7 Optimal SID-M+C FCR (%): 0.632 Optimal SID-M+C BWG (%): 0.652		

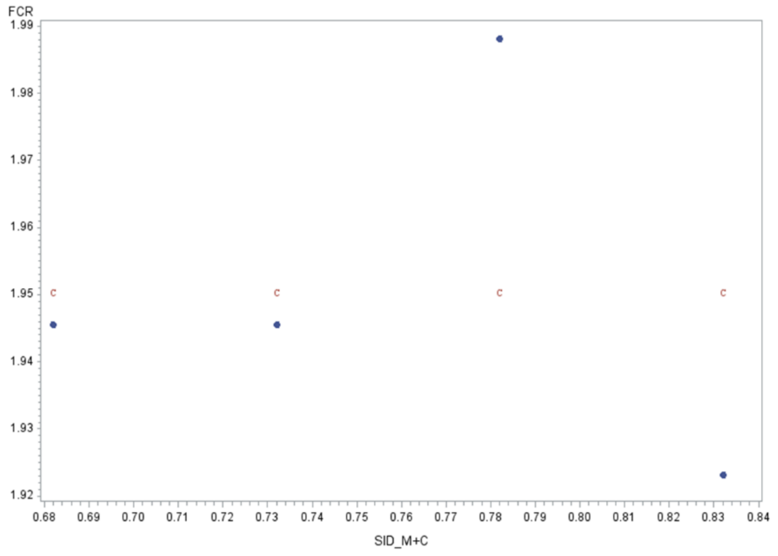
33. Albino et al. (1999) Trial 8 Optimal SID-M+C FCR (%): 0.632 Optimal SID-M+C BWG (%): 0.659		
34. Baker et al. (1996) Trial 1 Optimal SID-M+C FCR (%):Could not be estimated Optimal SID-M+C BWG (%): Could not be estimated		

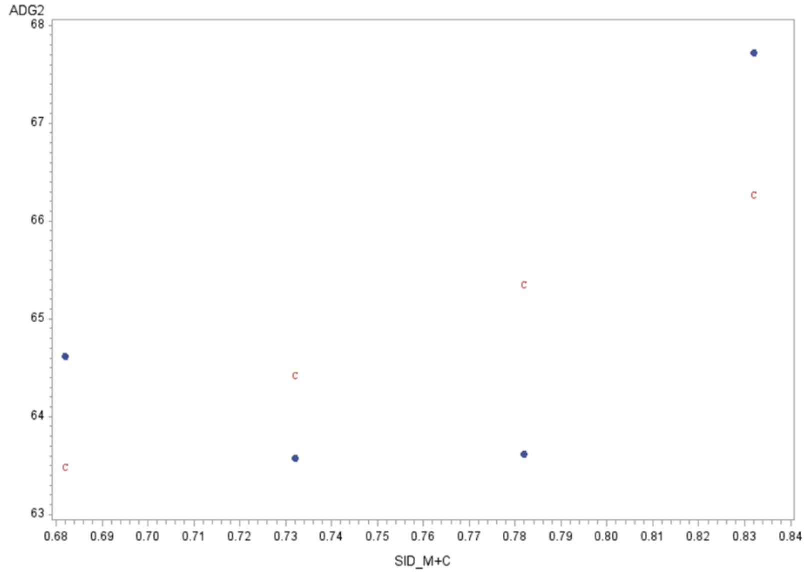
35. Baker et al. (1996) Trial 2 Optimal SID-M+C FCR (%): 0.756 Optimal SID-M+C BWG (%): 0.712		
36. Mendonca and Jensen (1989) Trial 1 Optimal SID-M+C FCR (%):Could not be estimated Optimal SID-M+C BWG (%): Could not be estimated		

37.
Mendonca and Jensen (1989) Trial 2

Optimal SID-M+C FCR (%):Could not be estimated

Optimal SID-M+C BWG (%): Could not be estimated

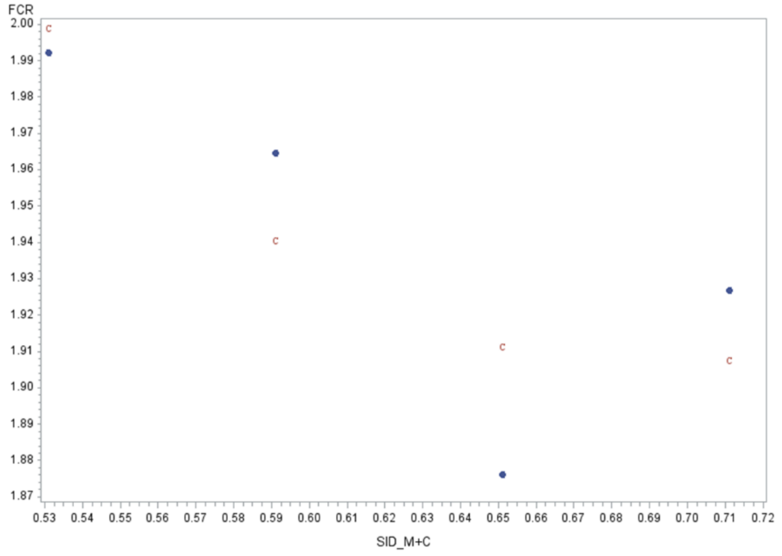


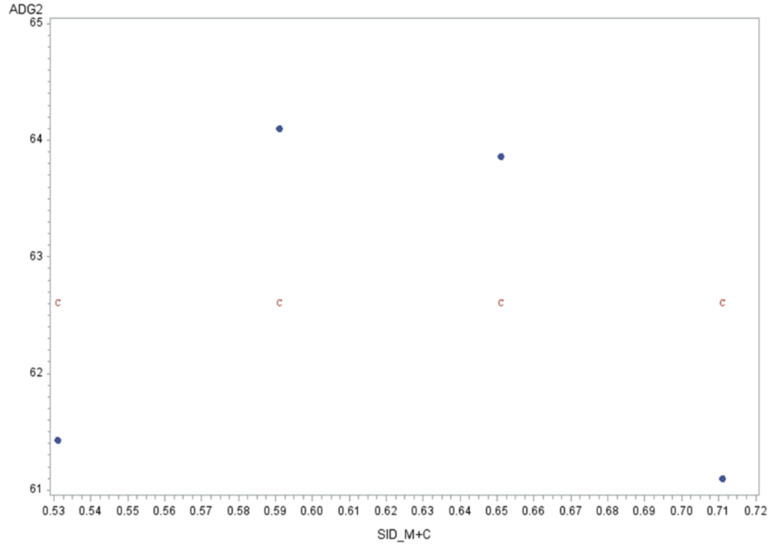


38.
Mendonca and Jensen (1989) Trial 3

Optimal SID-M+C FCR (%): 0.705

Optimal SID-M+C BWG (%): Could not be estimated





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<td>39.
Agostini et al. (2016)
Trial 1

Optimal SID-M+C FCR (%): 0.688 (not reliable estimate)

Optimal SID-M+C BWG (%): (not reliable estimate)</td>
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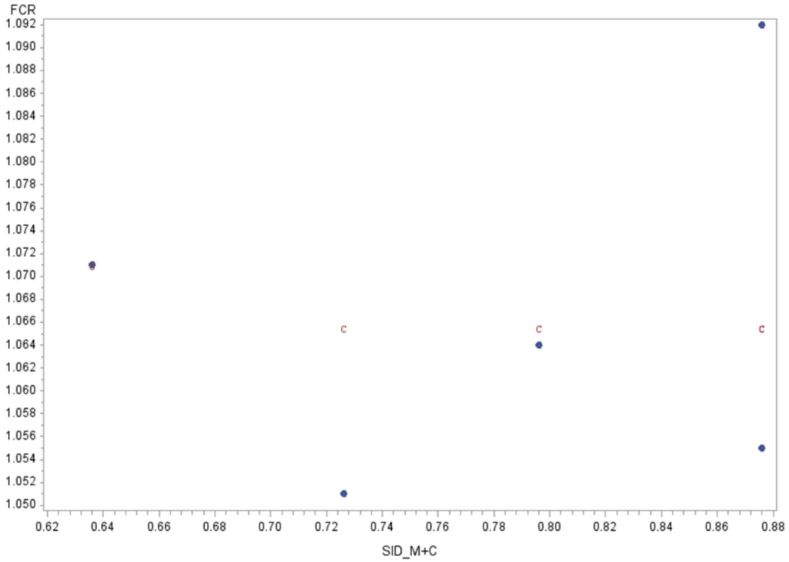

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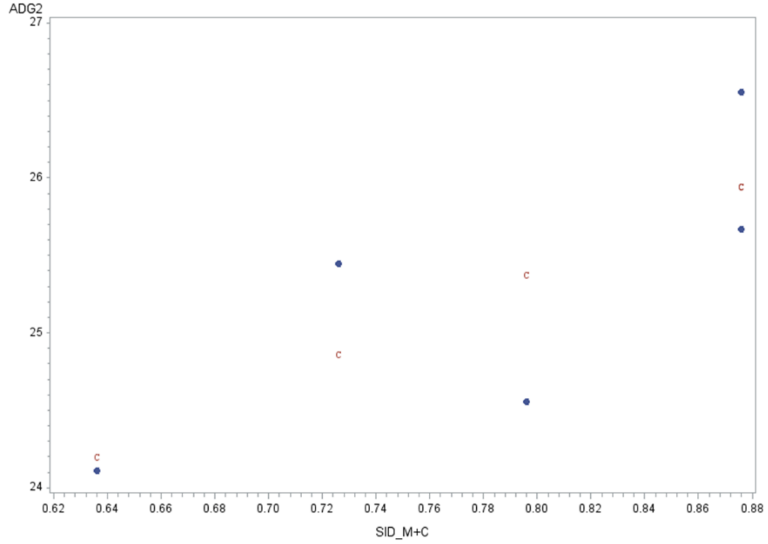

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<td>40.
Agostini et al. (2016)
Trial 2

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Optimal SID-M+C BWG (%): (not reliable estimate)</td>
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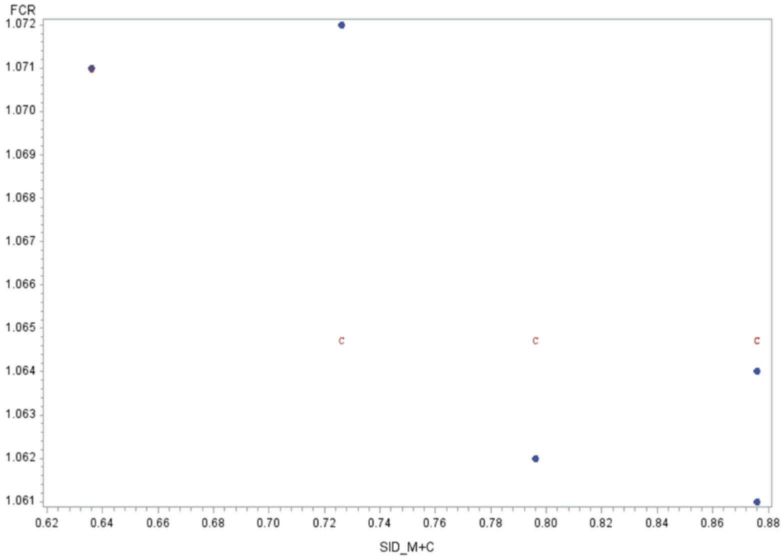

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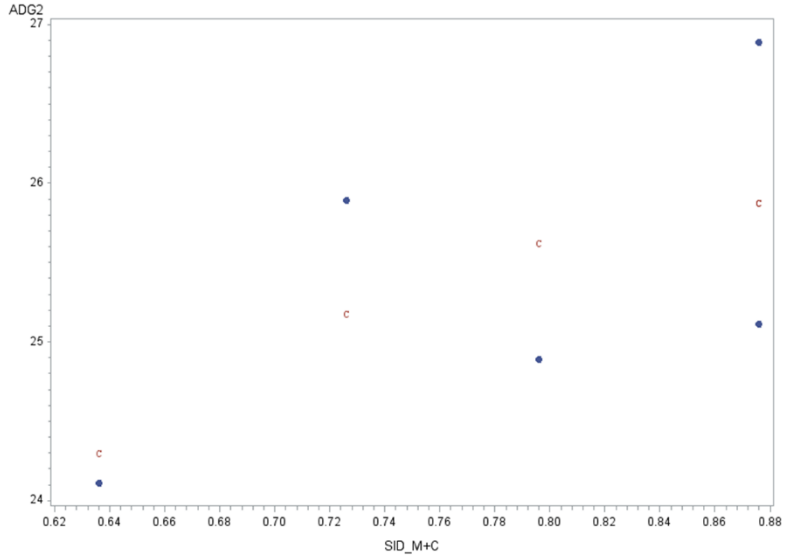

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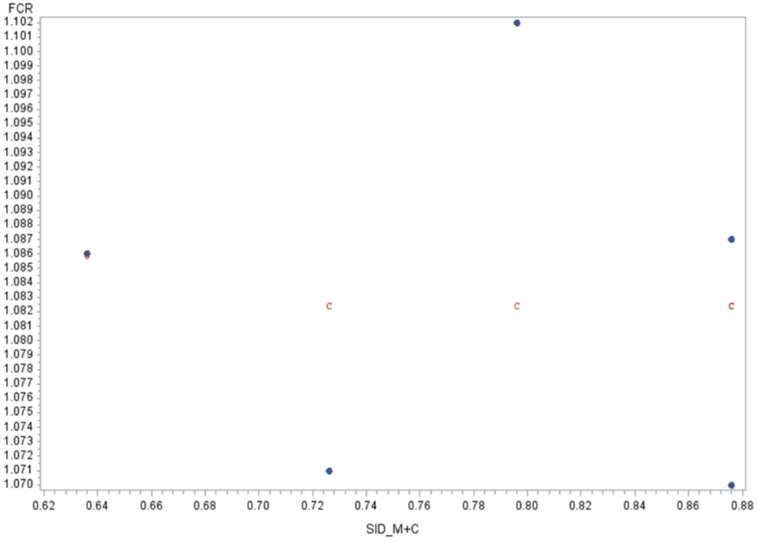
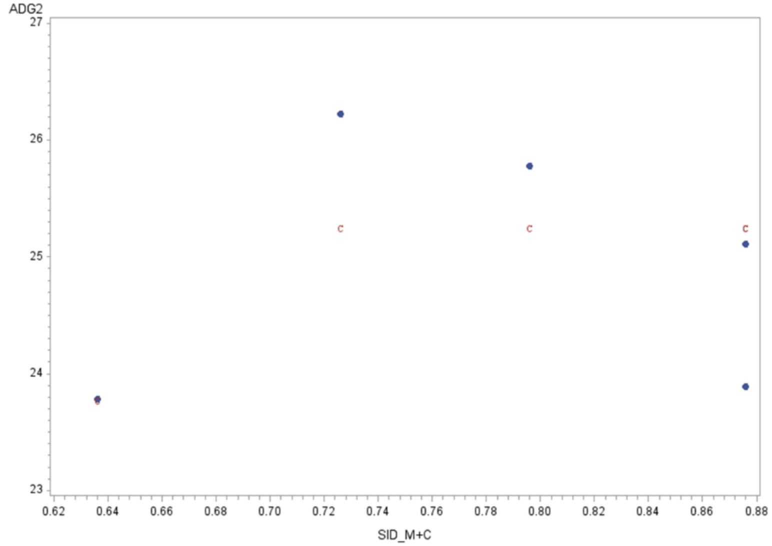
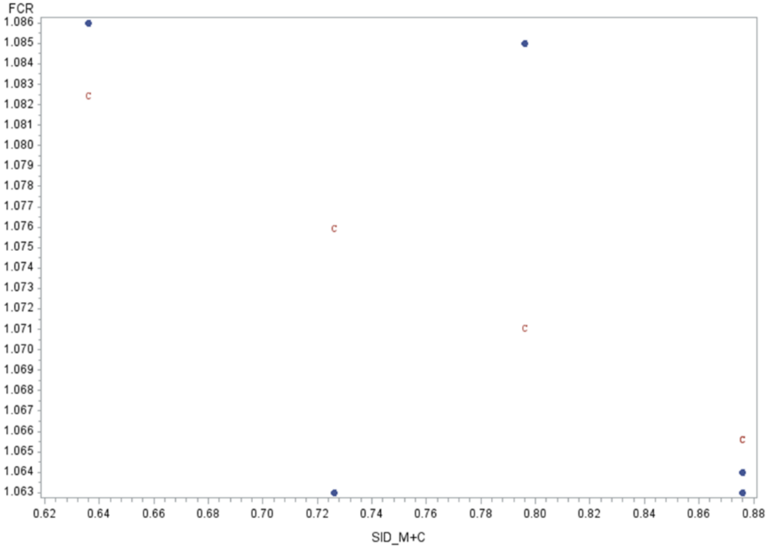
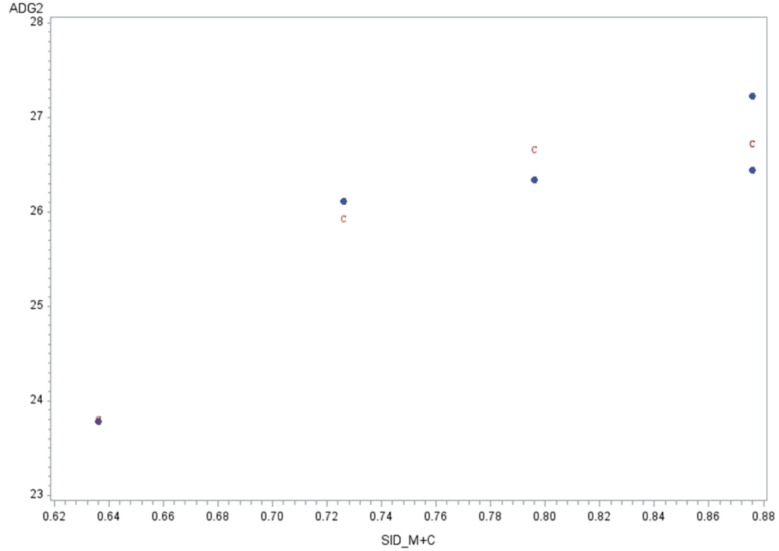
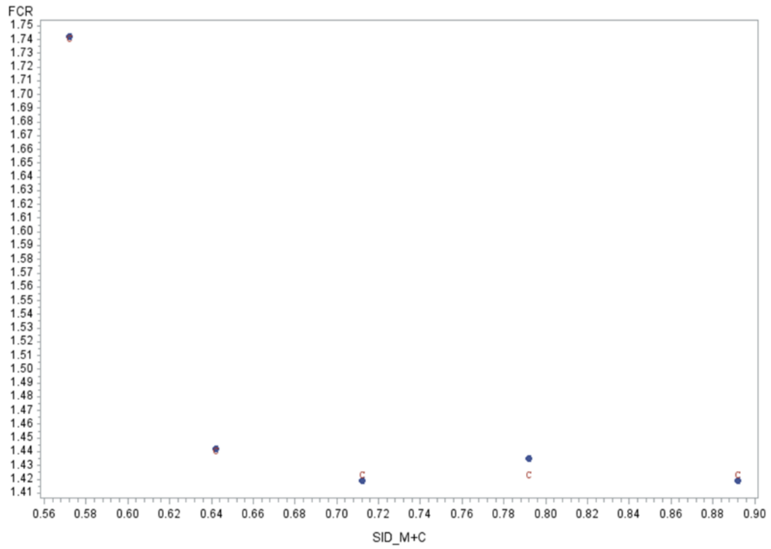
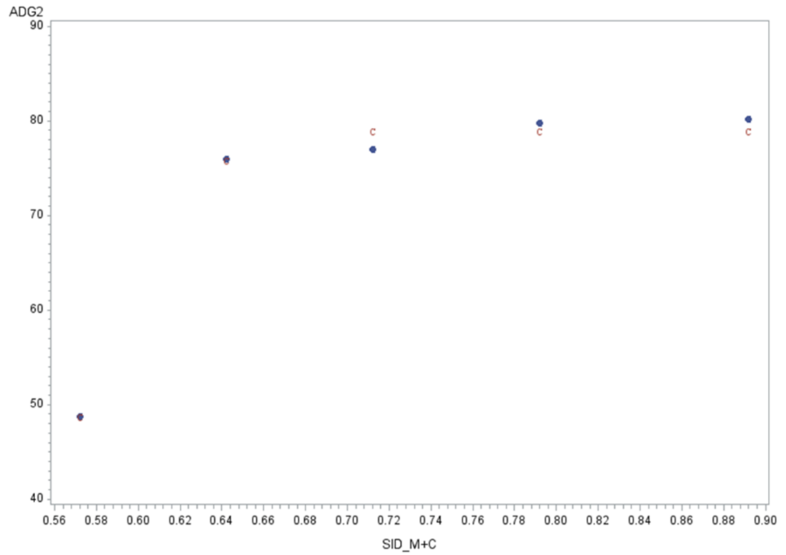
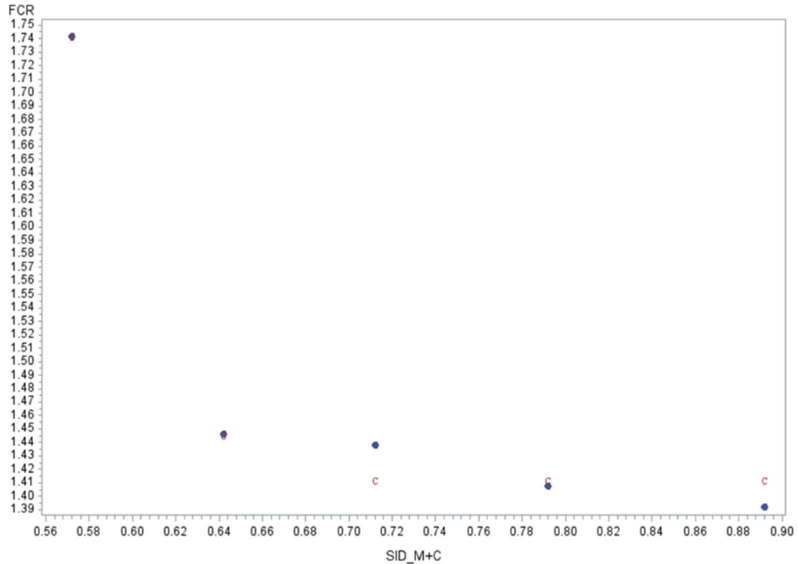
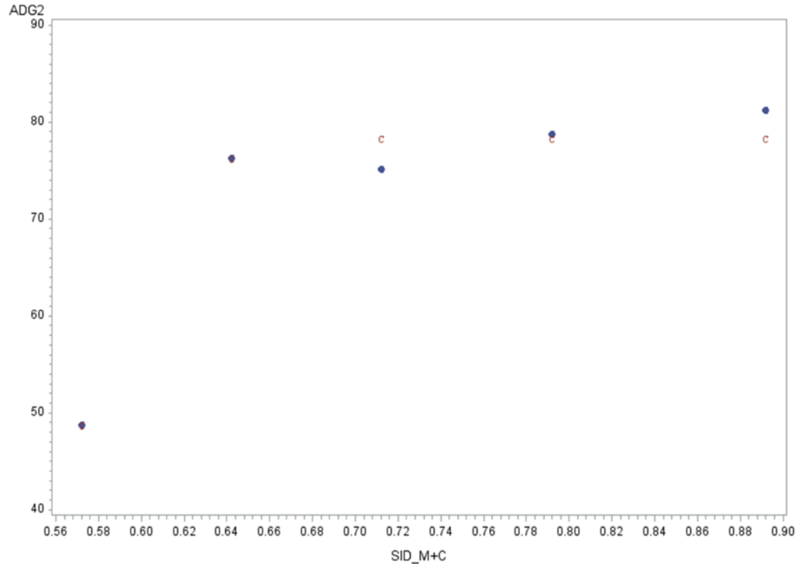
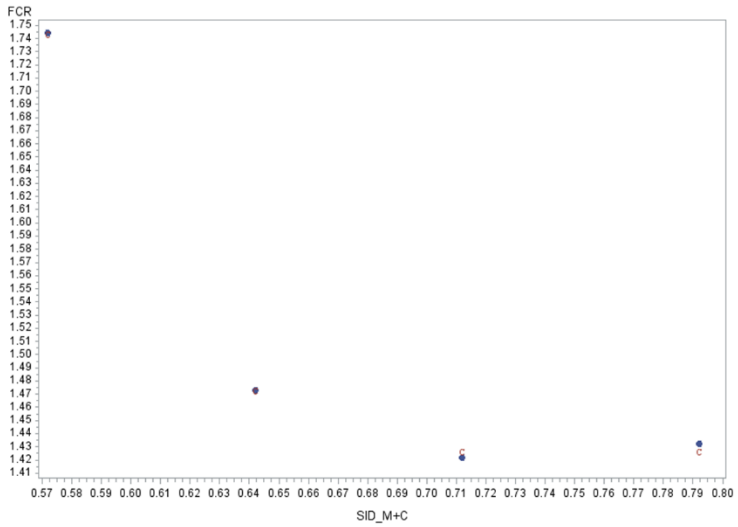
41. Agostini et al. (2016) Trial 3 Optimal SID-M+C FCR (%): 0.699 (not reliable estimate) Optimal SID-M+C BWG (%): 0.722 (not reliable estimate)		
42. Agostini et al. (2016) Trial 4 Optimal SID-M+C FCR (%): 3.546 (no reliable estimate) Optimal SID-M+C BWG (%): 0.823		

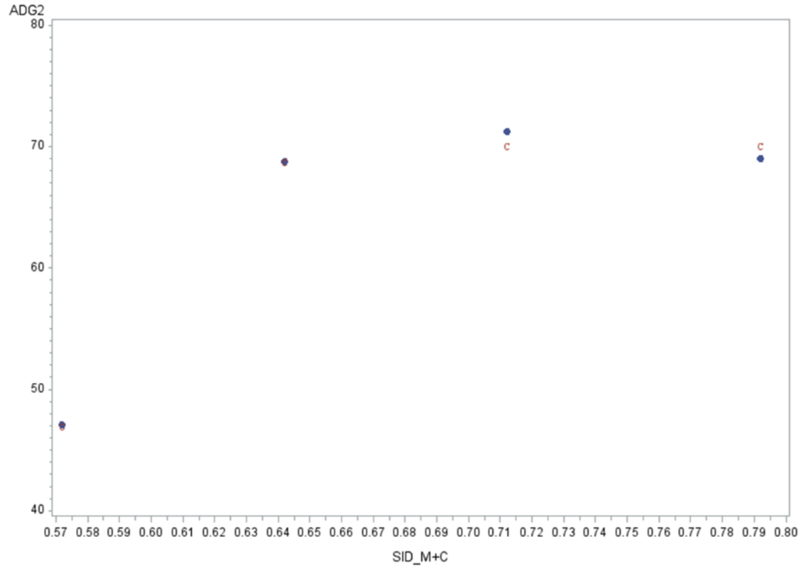
43. Agostini et al. (2016) Trial 5 Optimal SID- M+C FCR (%): 0.664 Optimal SID- M+C BWG (%): 0.674		
44. Agostini et al. (2016) Trial 6 Optimal SID- M+C FCR (%): 0.675 Optimal SID- M+C BWG (%): 0.667		

45.
Agostini et al. (2016)
Trial 7

Optimal SID-M+C FCR (%):
0.685

Optimal SID-M+C BWG (%):
0.664

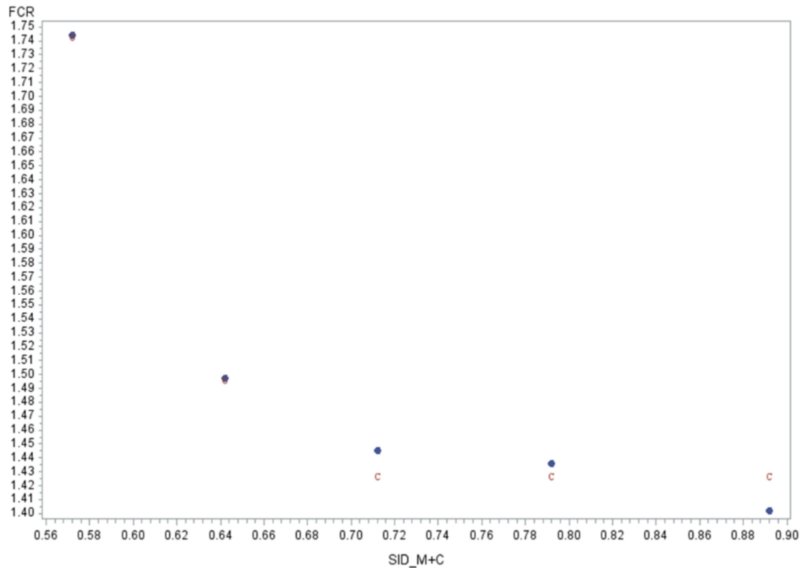


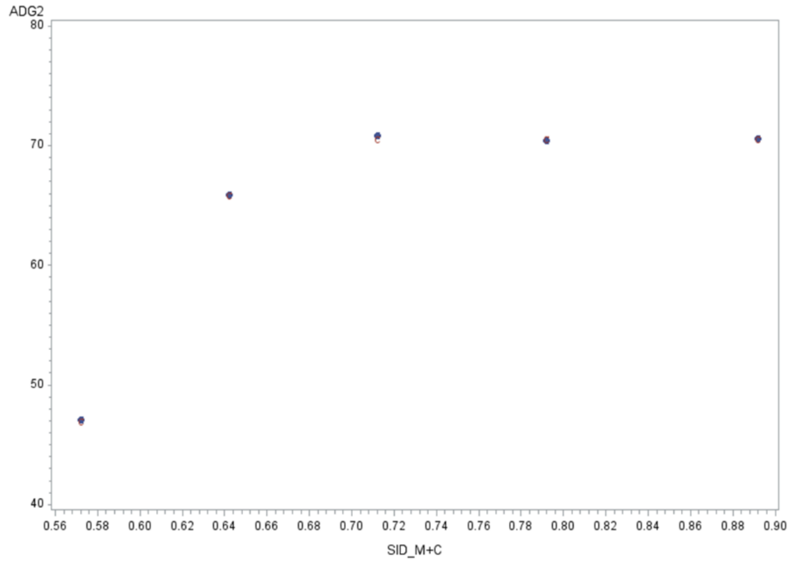


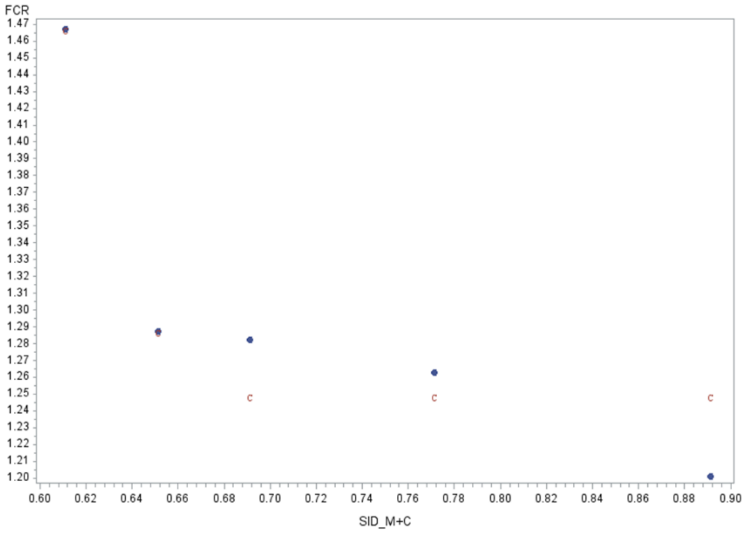
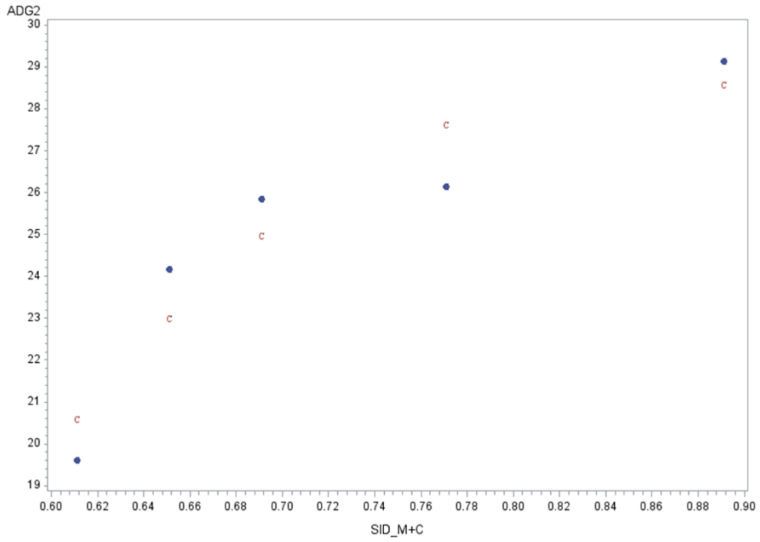
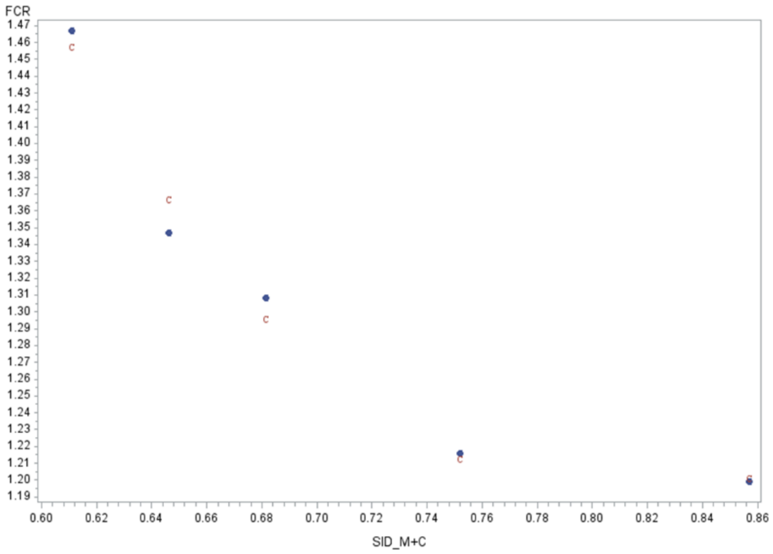
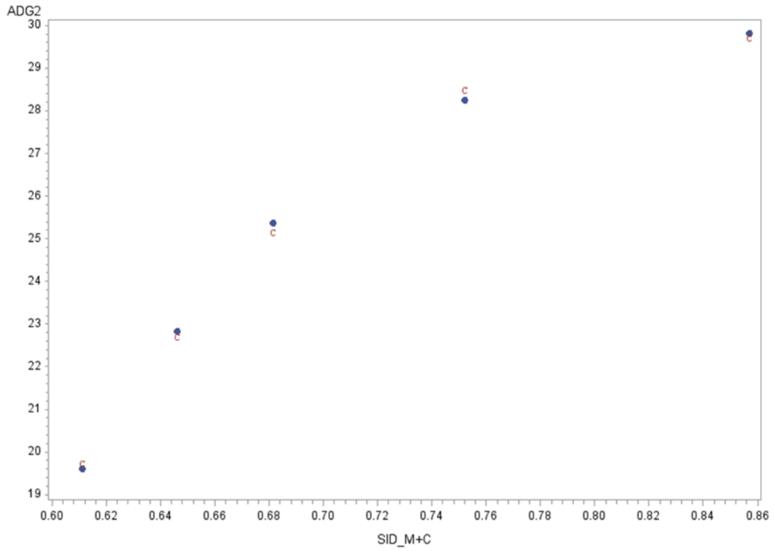
46.
Agostini et al. (2016)
Trial 8

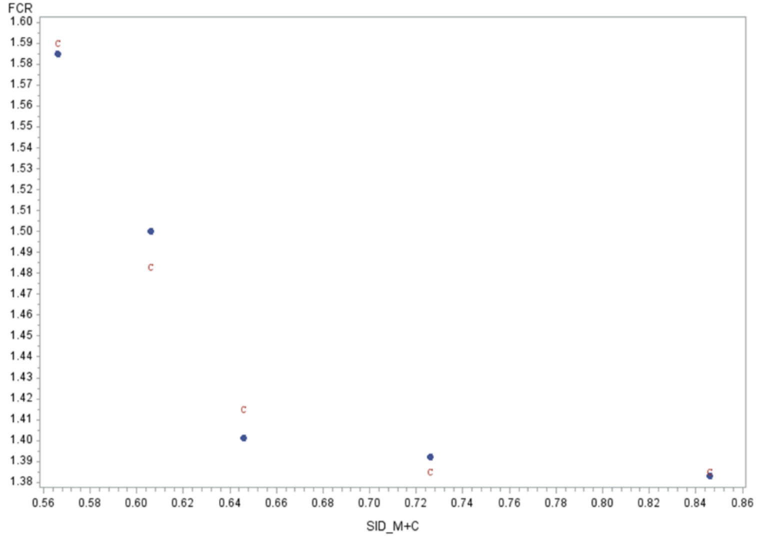
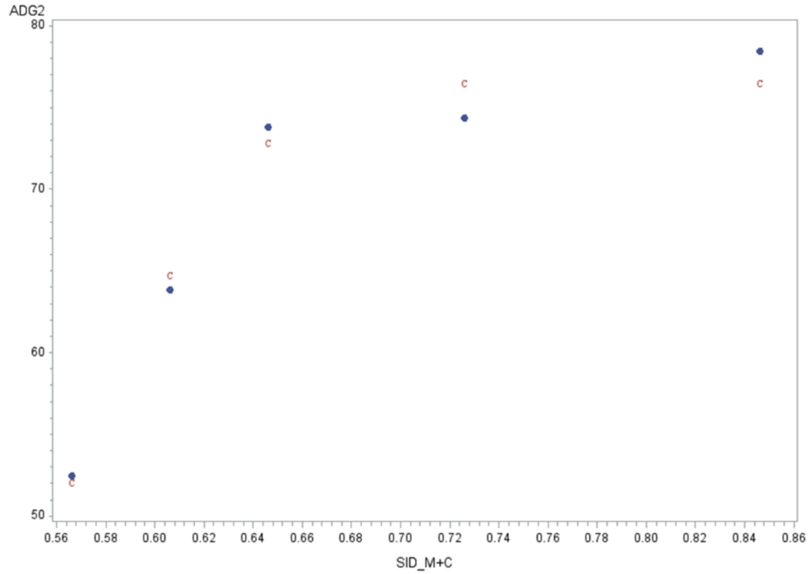
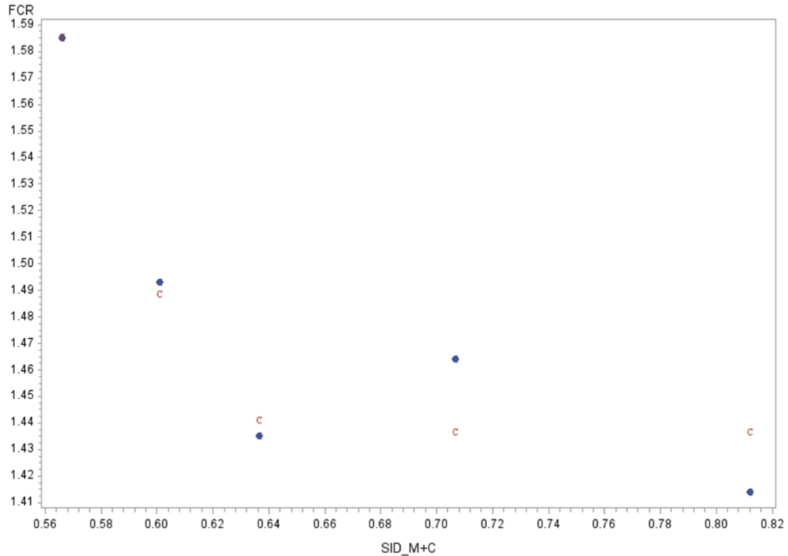
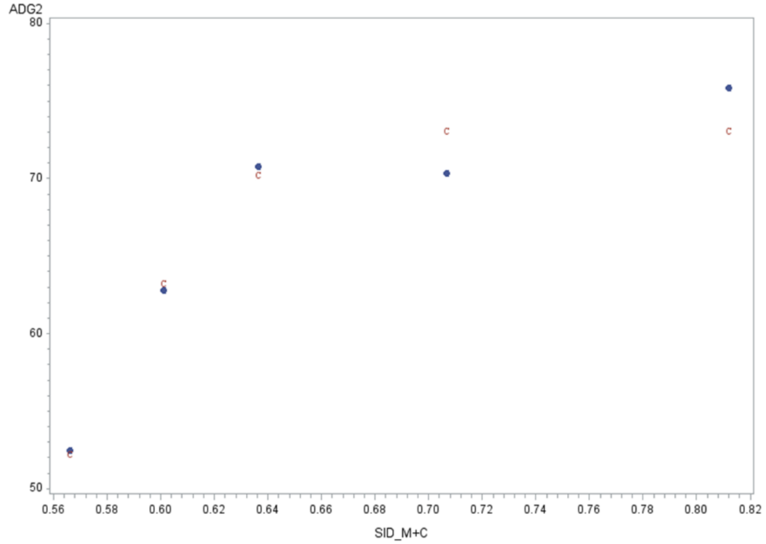
Optimal SID-M+C FCR (%):
0.704

Optimal SID-M+C BWG (%):
0.699





47. Zelenka et al. (2013) Trial 1 Optimal SID-M+C FCR (%): 0.680 Optimal SID-M+C BWG (%): 0.856		
48. Zelenka et al. (2013) Trial 2 Optimal SID-M+C FCR (%): 0.790 Optimal SID-M+C BWG (%):		

49. Zelenka et al. (2013) Trial 3 Optimal SID-M+C FCR (%): 0.696 Optimal SID-M+C BWG (%): 0.696		
50. Zelenka et al. (2013) Trial 4 Optimal SID-M+C FCR (%): 0.651 Optimal SID-M+C BWG (%): 0.678		

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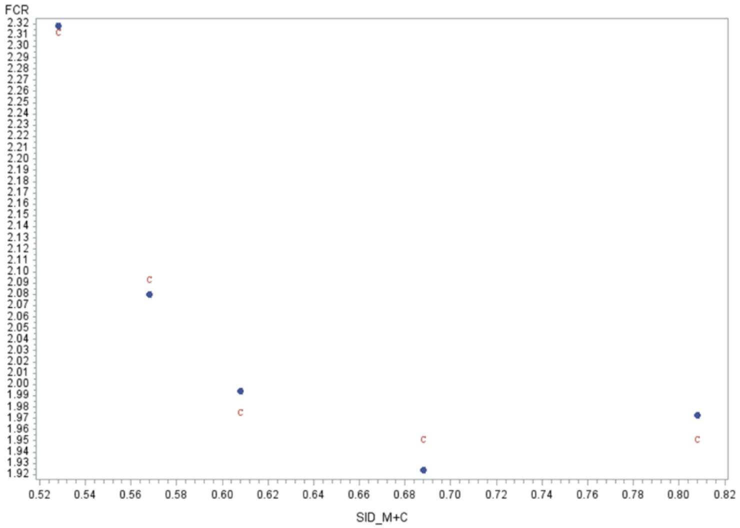
Zelenka et al. (2013)
Trial 5

Optimal SID-M+C FCR (%): 0.635

Optimal SID-M+C BWG (%): 0.638</td>
<td>
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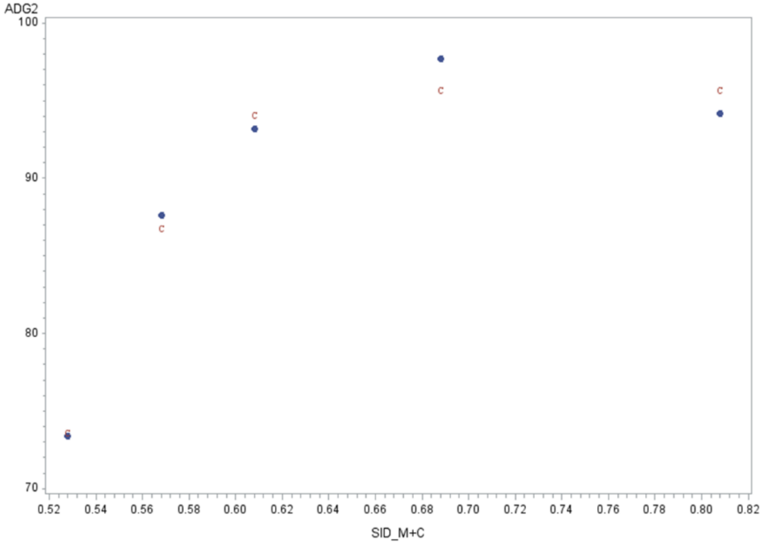
<td>
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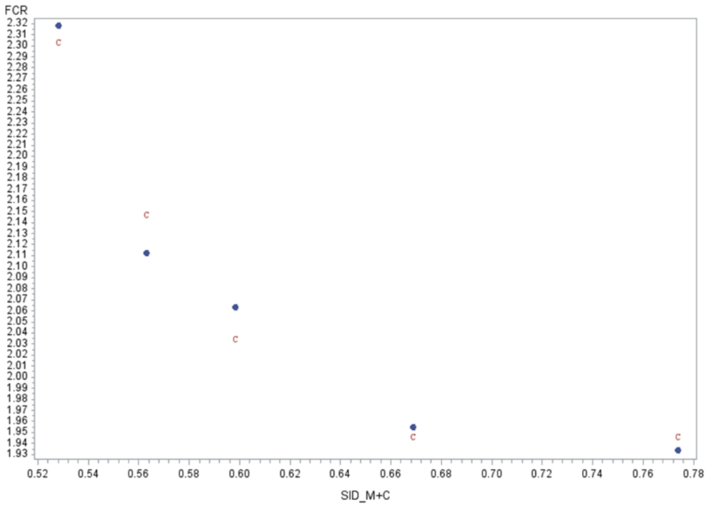
<td>52.
Zelenka et al. (2013)
Trial 6

Optimal SID-M+C FCR (%): 0.669

Optimal SID-M+C BWG (%): 0.661</td>
<td>
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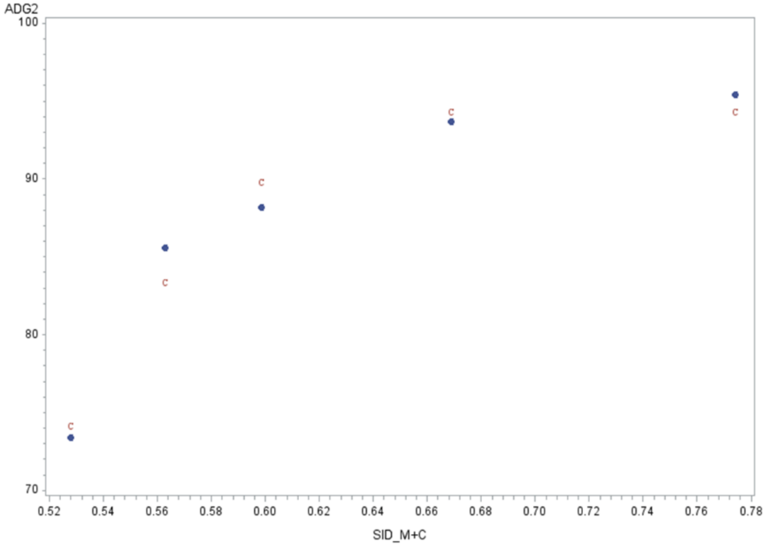
<td>
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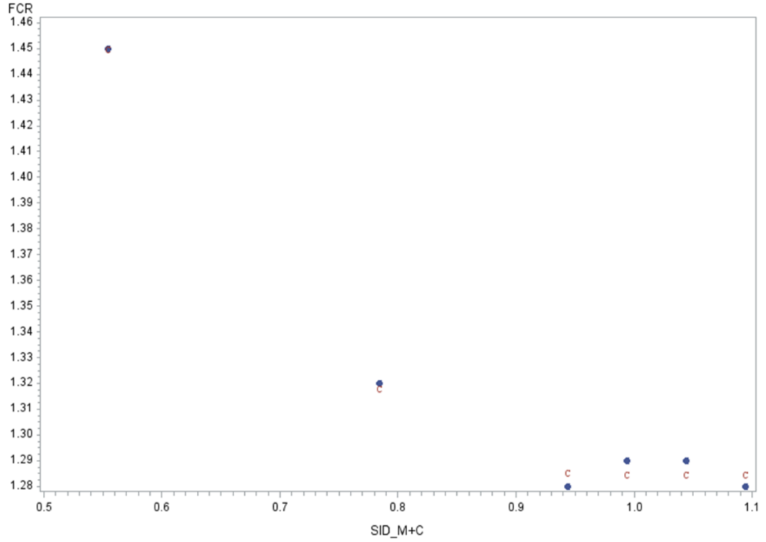
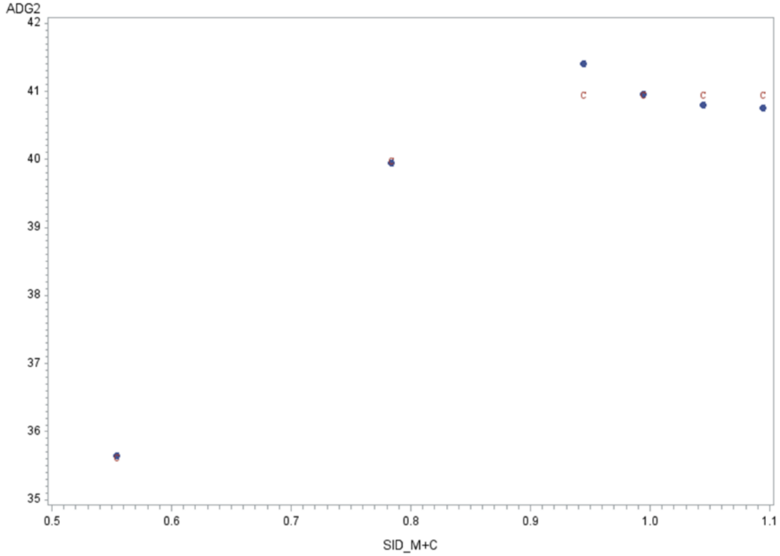
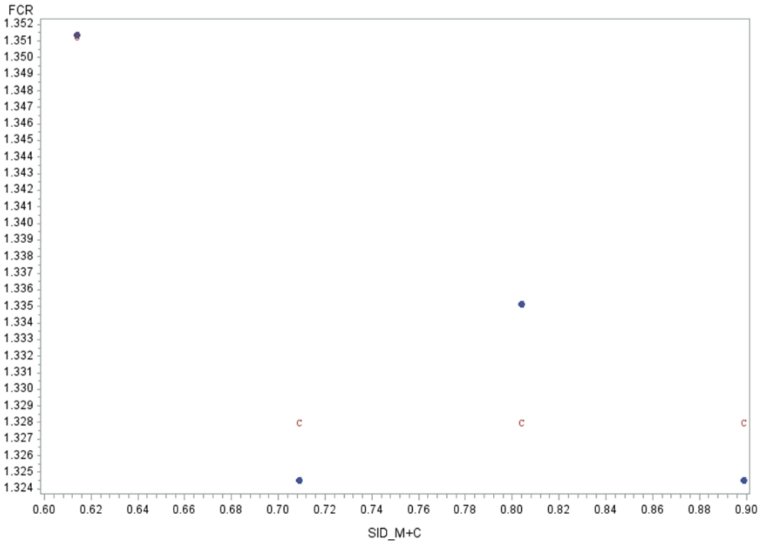
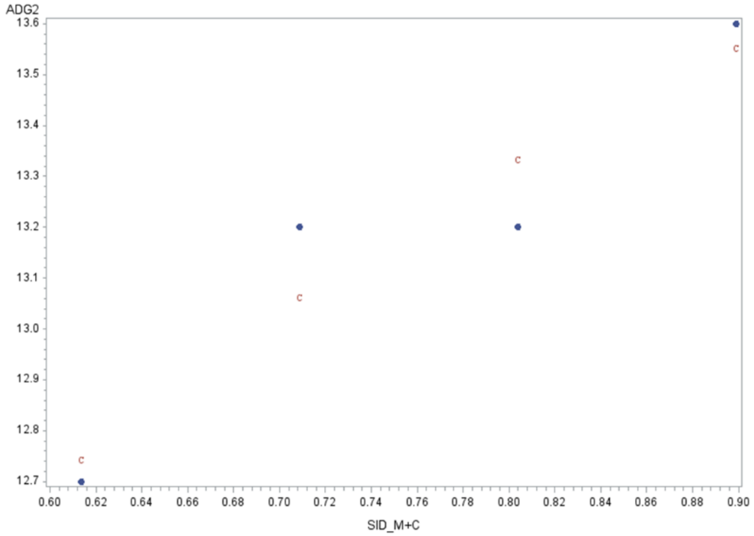
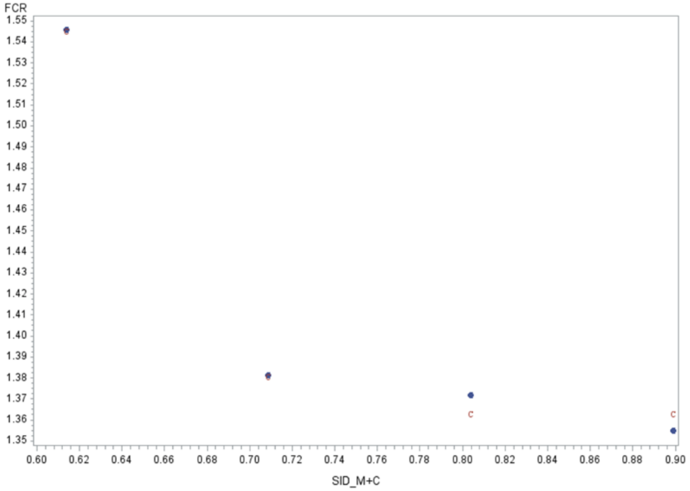
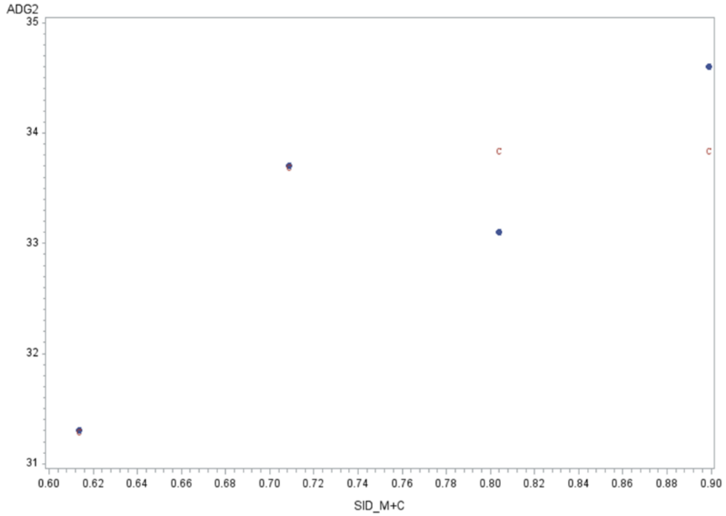
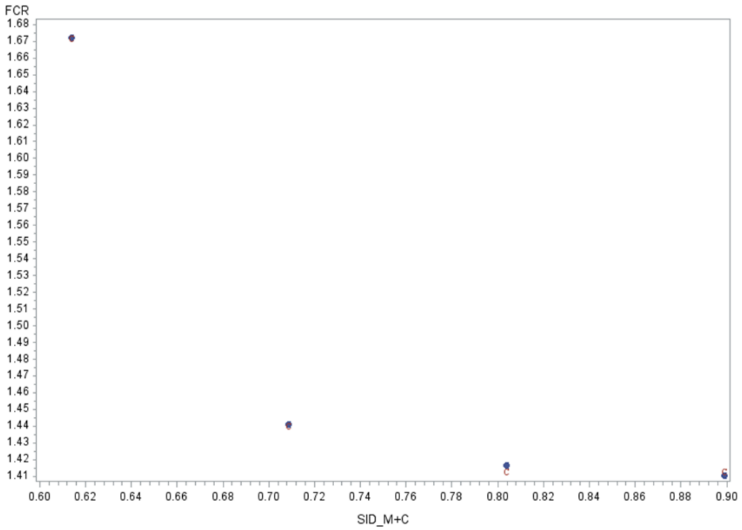
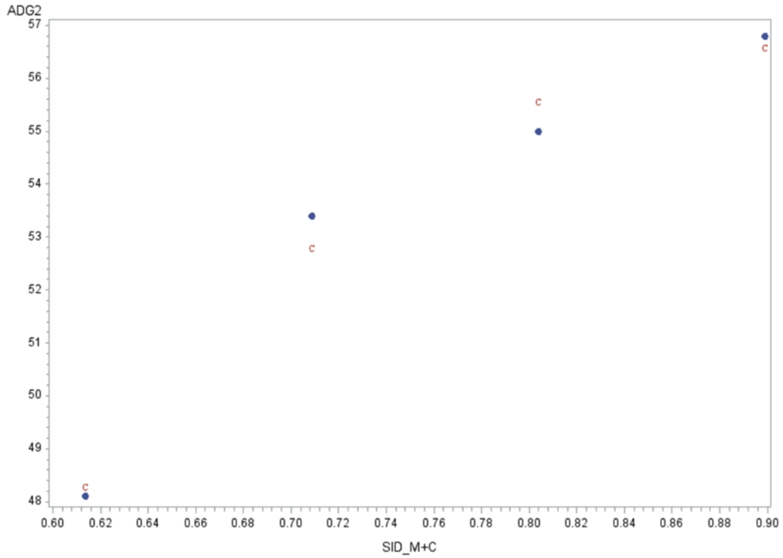
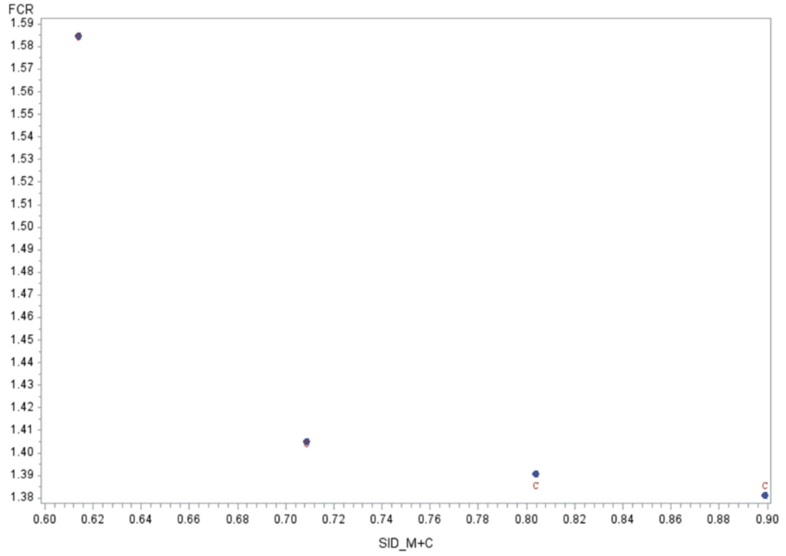
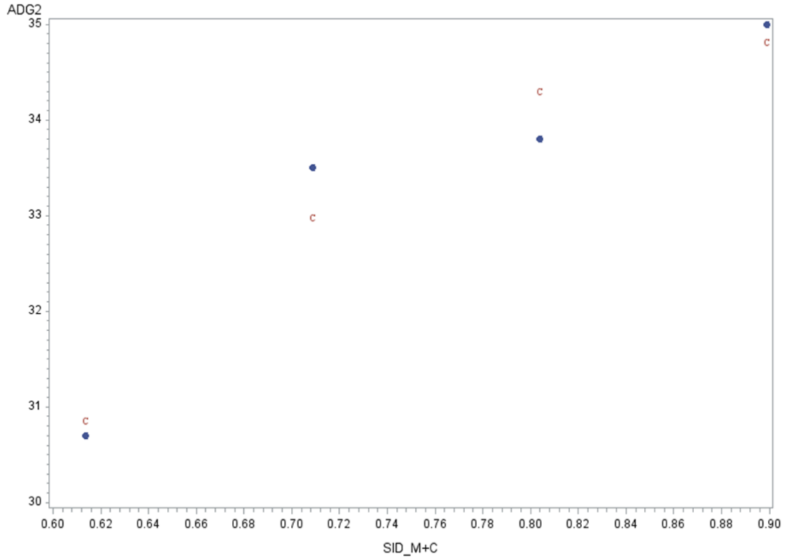
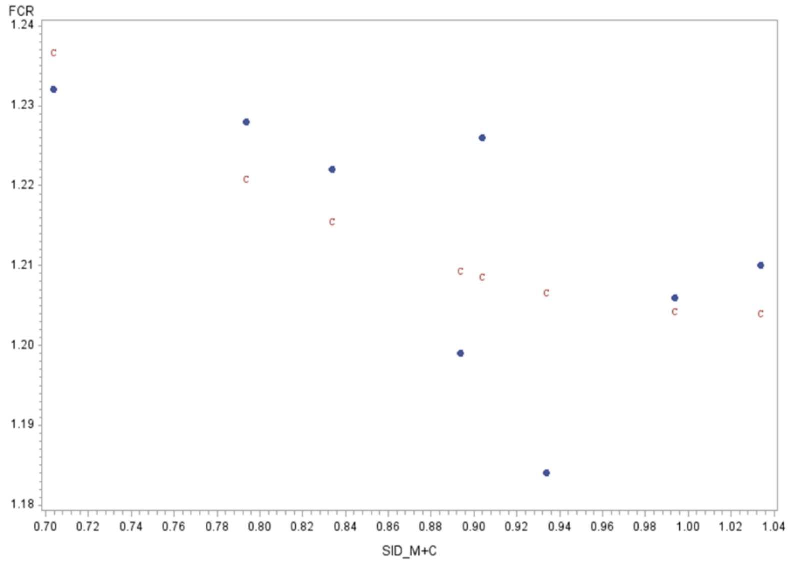
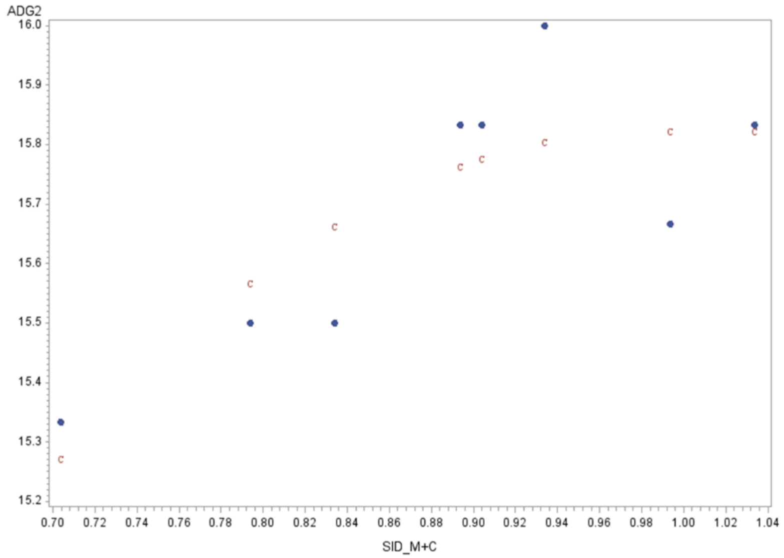
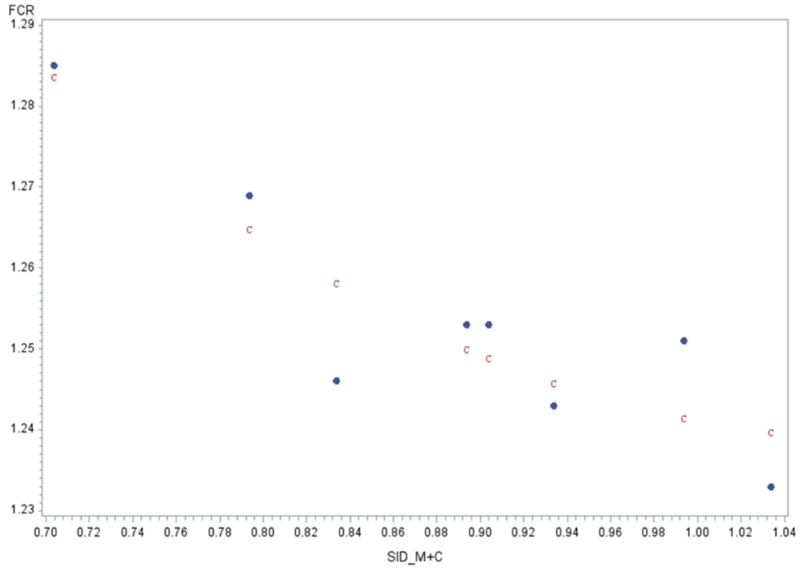
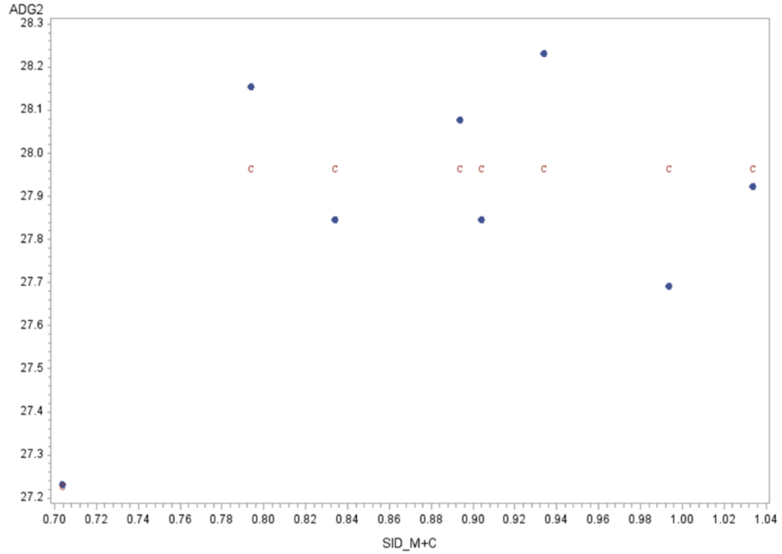
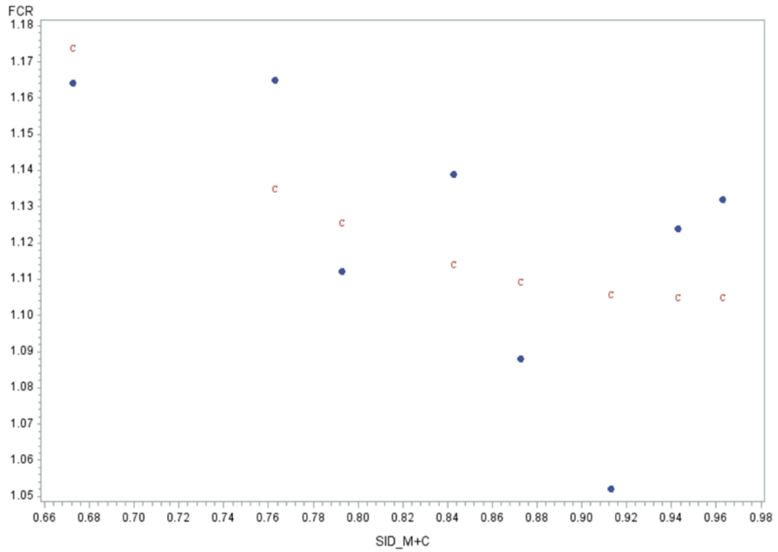
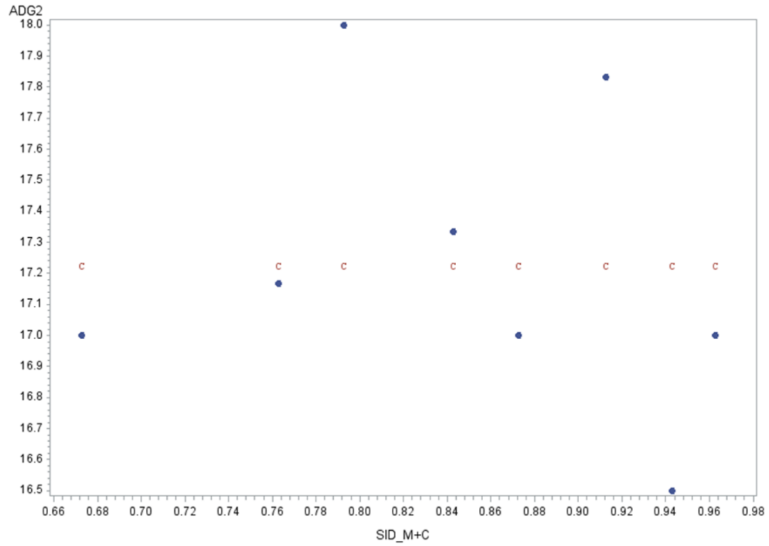
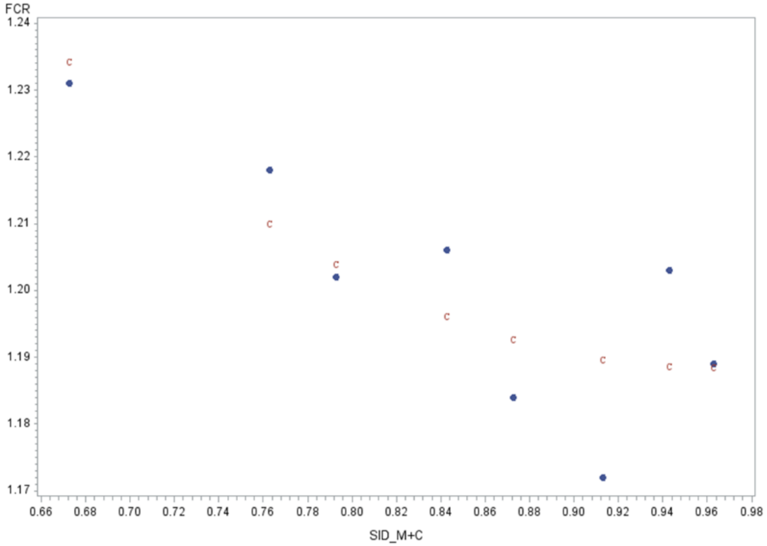
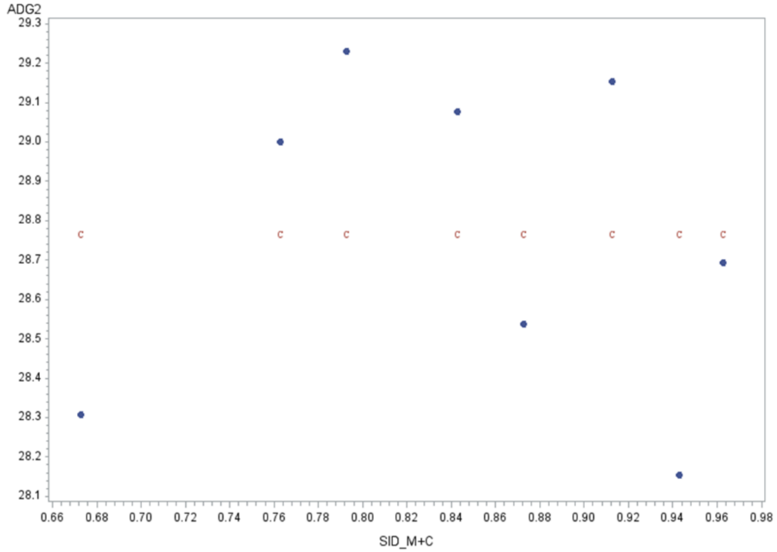
53. Rakangtong and Bunchasak (2011) Optimal SID-M+C FCR (%): 0.972 Optimal SID-M+C BWG (%): 0.955		
55. Shen et al. (2015) Trial 1 Optimal SID-M+C FCR (%): (no reliable estimate) Optimal SID-M+C BWG (%): (no reliable estimate)		

56. Shen et al. (2015) Trial 2 Optimal SID-M+C FCR (%): 0.752 Optimal SID-M+C BWG (%): 0.739		
57. Shen et al. (2015) Trial 3 Optimal SID-M+C FCR (%): 0.755 Optimal SID-M+C BWG (%): 0.907		

58. Shen et al. (2015) Trial 4 Optimal SID-M+C FCR (%): 0.751 Optimal SID-M+C BWG (%): 0.913		
59. Dozier and Mercier (2013) Trial 1 Optimal SID-M+C FCR (%): 1.024 Optimal SID-M+C BWG (%): 0.985		

60. Dozier and Mercier (2013) Trial 2 Optimal SID-M+C FCR (%): (no reliable estimate) Optimal SID-M+C BWG (%): (no reliable estimate)		
61. Dozier and Mercier (2013) Trial 3 Optimal SID-M+C FCR (%): 0.939 Optimal SID-M+C BWG (%): (could not be estimated		

62. Dozier and Mercier (2013) Trial 4 Optimal SID-M+C FCR (%): 0.939 Optimal SID-M+C BWG (%): (could not be estimated)		

Appendix B. SID-M+C model estimates using the quadratic broken-line model for minimum FCR and maximum BWG

SID-M+C model estimates using the quadratic broken-line model for minimum FCR

Trial nr.	Estimate L	Std. Err. L	Estimate R	Std. Err. R	Estimate U	Std. Err. U	R^2
1	1.702	0.0111	0.730	0.0291	4.4	1.09	0.986
2	1.584	0.0108	0.817	0.0967	1.9	1.49	0.952
3	1.587	0.0033	0.669	0.0098	16.1	2.99	0.998
4	1.030	0.0171	0.865	0.1222	3.6	6.21	0.638
5	1.432	0.0160	0.700	0.0000	4.7	2.98	0.387
6	1.771	0.0474	0.772	0.1045	7.0	7.43	0.805
7							
8	1.243	0.0052	0.906	0.0232	1.9	0.26	0.997
9	1.265	0.0188	0.890	0.0817	2.1	1.11	0.961
10	1.485	0.0202	1.082	0.0575	3.1	1.06	0.976
11	1.596	0.0517	0.956	0.2037	4.8	9.05	0.612
12	1.371	0.0144	0.726	0.0323	9.3	3.30	0.985
13	1.383	0.0084	0.738	0.0238	6.9	1.70	0.992
14	1.211	0.0135	0.819	0.0853	1.7	1.08	0.946
15	1.228	0.0033	0.792	0.0170	2.5	0.34	0.998
16	1.931	0.0210	0.806	0.1119	1.8	1.29	0.927
17	1.965	0.0098	0.698	0.0412	4.6	1.94	0.978
18	1.332	0.0293	0.428	0.0238	25.9	7.38	0.972
19	1.328	0.0278	0.406	0.0124	58.4	9.96	0.990
20	1.545	0.0028	0.768	0.0120	3.8	0.52	0.996
21	1.477	0.0118	0.828	0.0380	3.1	0.95	0.979
22	1.691	0.0108	0.832	0.0824	0.7	0.30	0.997
23							
24							
25							
26	1.505	0.0104	0.705	0.0176	22.3	7.02	0.983
27	1.529	0.0347	0.740	0.0728	11.9	11.86	0.835
28	1.537	0.0234	0.701	0.0592	15.6	17.12	0.822
29	1.571	0.0157	0.684	0.0352	21.9	16.39	0.916
30	2.257	0.0235	0.691	0.1408	4.4	8.96	0.565
31	2.463	0.0231	0.619	0.1022	22.5	62.48	0.646
32	2.231	0.0398	0.632	0.0629	37.7	55.34	0.767
33	2.442	0.0300	0.565	.	260.3	211.50	0.275
34	-3.218	124.5000	3.370	61.9127	0.7	16.10	0.887
35	1.647	0.0136	0.756	0.0175	8.6	1.23	0.995
36	1.044	48.5809	3.674	158.8000	0.1	5.43	0.864
37							
38	1.908	0.0433	0.681	0.1950	4.0	10.06	0.705
39	1.066	0.0092	0.688	.	2.0	7.53	0.023

Continued: SID-M+C model estimates using the quadratic broken-line model for minimum FCR

Trial Nr.	Estimate L	StdErr L	Estimate R	StdErr R	Estimate U	StdErr U	R^2
40	1.065	0.0025	0.678	.	3.5	3.14	0.295
41	1.083	0.0076	0.699	.	0.9	4.34	0.014
42	0.976	7.5892	3.546	217.5000	0.0	0.98	0.350
43	1.424	0.0053	0.664	0.0084	37.9	6.83	0.998
44	1.413	0.0135	0.675	0.0190	31.2	11.45	0.983
45	1.427	0.0050	0.685	0.0063	24.8	2.71	0.999
46	1.428	0.0131	0.704	0.0212	18.3	6.03	0.987
47	1.249	0.0245	0.680	0.0308	46.1	41.66	0.909
48	1.202	0.0167	0.790	0.0301	8.0	2.64	0.986
49	1.386	0.0118	0.696	0.0215	12.2	4.15	0.982
50	1.437	0.0172	0.651	0.0332	20.4	16.03	0.901
51	1.953	0.0206	0.635	0.0191	31.3	11.25	0.982
52	1.947	0.0249	0.669	0.0285	18.1	7.72	0.974
53	1.285	0.0032	0.972	0.0347	0.9	0.16	0.995
55	1.328	0.0035	0.686	.	4.4	1.34	0.845
56	1.363	0.0084	0.752	0.0248	9.5	3.33	0.994
57	1.413	0.0030	0.755	0.0063	13.0	1.12	1.000
58	1.386	0.0048	0.751	0.0131	10.5	1.95	0.998
59	1.204	0.0116	1.024	0.2647	0.3	0.51	0.443
60	1.239	0.0109	1.079	0.1845	0.3	0.27	0.814
61	1.105	0.0219	0.939	0.2311	1.0	1.73	0.388
62	1.189	0.0089	0.960	0.1419	0.6	0.54	0.691

SID-M+C model estimates using the quadratic broken-line model for maximum BWG

Trial nr.	Estimate L	Std. Err. L	Estimate R	Std. Err. R	Estimate U	Std. Err. U	R^2
1	92.7	0.38	0.653	0.0157	-526	104.9	0.992
2	29.8	0.51	0.812	0.1677	-53	75.2	0.864
3	28.1	0.10	0.740	0.0173	-125	26.0	0.995
4							
5							
6	88.8	1.41	0.717	0.0680	-524	493.2	0.852
7	114.2	5.51	0.607	0.2908	-1438	10453.8	0.155
8	47.7	0.15	0.858	0.0096	-164	11.4	0.999
9	45.9	0.53	0.795	0.0345	-264	85.2	0.988
10	46.0	0.86	0.967	0.0710	-208	131.3	0.932
11	46.0	0.38	0.947	0.0237	-328	75.4	0.991
12	48.1	0.17	0.703	0.0067	-631	52.3	0.999
13	45.2	0.64	0.778	0.0365	-252	78.1	0.988
14	47.2	0.96	0.695	0.0397	-665	339.4	0.963
15	46.0	0.49	0.713	0.0271	-413	131.1	0.988
16	85.4	1.04	0.669	0.1125	-215	284.5	0.824
17	74.9	0.97	0.658	0.0827	-301	310.4	0.891
18	42.5	2.28	0.508	0.0525	-505	217.0	0.930
19	39.3	2.22	0.502	0.0494	-539	222.5	0.936
20	43.1	0.16	0.732	0.0195	-194	54.8	0.983
21	44.3	0.63	0.707	0.0286	-706	345.8	0.956
22	95.1	0.19	0.684	0.0338	-120	57.1	0.986
23							
24							
25							
26	34.9	0.40	0.733	0.0235	-459	154.9	0.979
27	31.7	0.61	0.753	0.0537	-243	165.5	0.910
28	34.1	0.11	0.769	0.0095	-212	23.5	0.997
29	30.9	0.05	0.696	0.0035	-544	36.1	0.999
30							
31	60.2	0.53	0.676	0.1539	-112	274.6	0.490
32	71.1	0.99	0.652	0.0667	-623	806.7	0.769
33	61.1	0.59	0.659	0.1279	-180	422.6	0.501
34							
35	68.0	1.15	0.712	0.0335	-528	177.9	0.976
36	66.6	1.75	0.750	0.2351	-131	413.8	0.562
37							
38							
39							
40	25.9	1.38	0.910	0.5801	-21	82.0	0.397
41	25.3	0.51	0.722	.	-200	154.0	0.359
42	26.7	0.32	0.823	0.0701	-83	62.1	0.931
43	79.0	0.99	0.674	0.0152	-2880	847.8	0.992
44	78.3	1.76	0.667	0.0287	-3270	1940.9	0.973
45	70.1	1.14	0.664	0.0211	-2701	1188.9	0.993

Continued: SID-M+C model estimates using the quadratic broken-line model for maximum BWG

Trial Nr.	Estimate L	StdErr L	Estimate R	StdErr R	Estimate U	StdErr U	R^2
46	70.6	0.12	0.699	0.0024	-1466	57.5	1.000
47	28.6	1.63	0.856	0.1176	-134	125.3	0.885
48	29.7	0.26	0.827	0.0132	-213	25.3	0.998
49	76.5	1.58	0.696	0.0244	-1438	553.1	0.977
50	73.1	1.98	0.678	0.0308	-1669	942.4	0.952
51	95.8	1.36	0.638	0.0208	-1830	699.5	0.979
52	94.4	1.56	0.661	0.0298	-1136	531.0	0.967
53	41.0	0.15	0.955	0.0513	-33	8.6	0.988
55							
56	33.9	0.75	0.739	0.1708	-162	425.8	0.807
57	56.6	0.93	0.907	0.0779	-97	48.3	0.982
58	34.8	0.88	0.913	0.1543	-44	42.1	0.942
59	15.8	0.10	0.985	0.1277	-7	6.3	0.704
60	28.0	0.07	0.770	.	-169	47.2	0.680
61							
62							