Chapter 7: Investigating backscattered intensity of Airborne LiDAR

There are four survey locations within the study area (Fig. 7.1). MF on the lowest floodplain closest to the modern channel junction, FF upstream and on the low floodplain adjacent to the River Trent, MTF in one of the large palaeochannel belts at the edge of the floodplain and VF on terrace 1, of which the results from MF, FF and MTF are discussed. Results for area VF are incomplete and are not considered herein (Fig. 7.1). This chapter investigates the relationships of NIR wavelengths to soil moisture and organic content of surface soils. Such data feeds into understanding the NIR reflectance patterns seen in LiDAR intensity data and can be partially used to assess its effectiveness at identifying organic rich water saturated deposits.

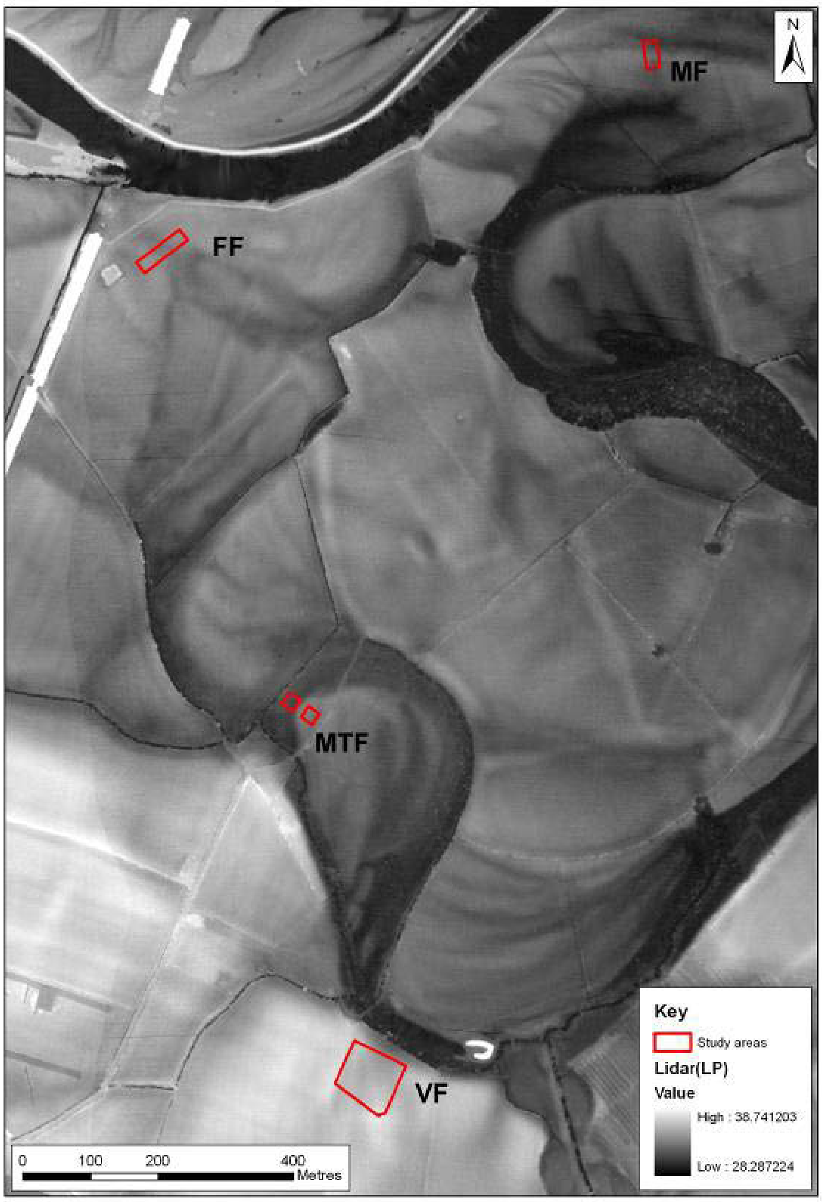


Fig 7.1: Lockington study area. LiDAR LPG elevation data with detailed LiDAR intensity study areas highlighted in red.

7.1 Toposil Moisture and Intensity: Broad Area Survey

Examination of the relationship between volumetric soil moisture and intensity for the entire study area shows a highly dispersed scatter (Fig. 7.2) with only a weak correlation (R^2 = 0.08) between soil moisture and LiDAR intensity. Clearly the diversity of sediment type and geomorphological feature across the study area is unlikely to be represented by examination of these data in aggregate.

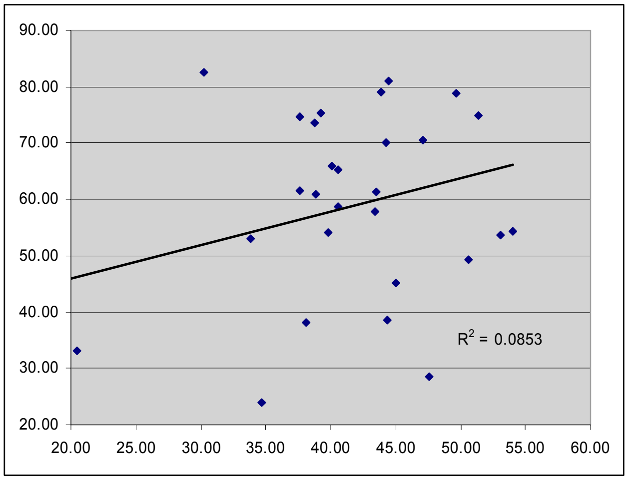


Fig 7.2: Scatter plot of LiDAR intensity (y) and volumetric soil moisture (x) for study area.

Examination of data for just the Hemington Terrace (Fig. 7.3) shows a similar weak correlation (R^2 = 0.08) between soil moisture and LiDAR intensity. However, examination of data for just the alluvium indicates a stronger negative correlation (R^2 = 0.22) between soil moisture and LiDAR intensity (Fig. 7.4).

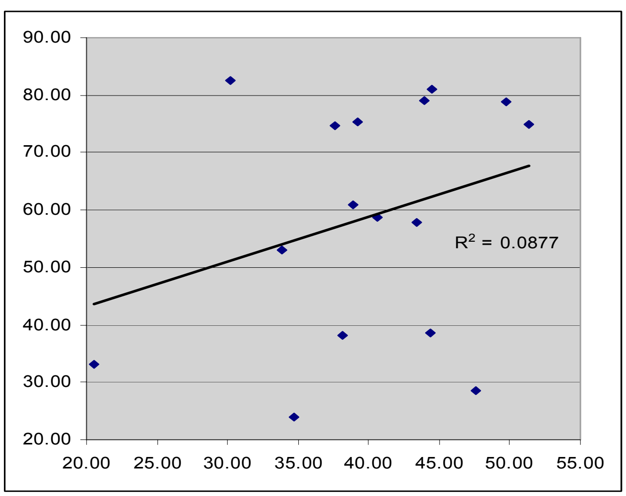


Fig 7.3: Scatter plot of LiDAR intensity (y) and volumetric soil moisture (x) for Hemington Terrace only.

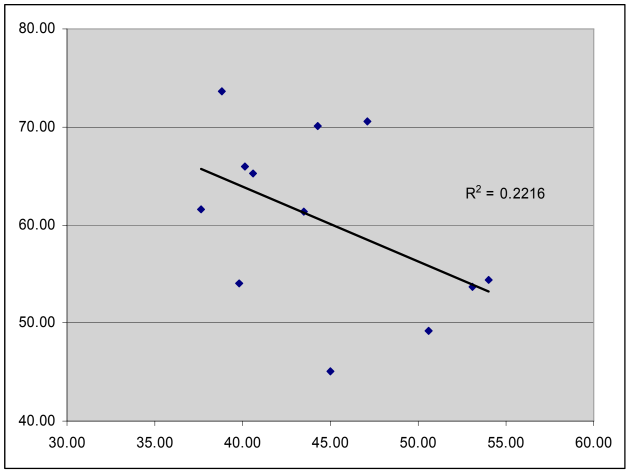


Fig 7.4: Scatter plot of LiDAR intensity (y) and volumetric soil moisture (x) for alluvium only.

Fig 7.5: Lockington, selected sample locations.

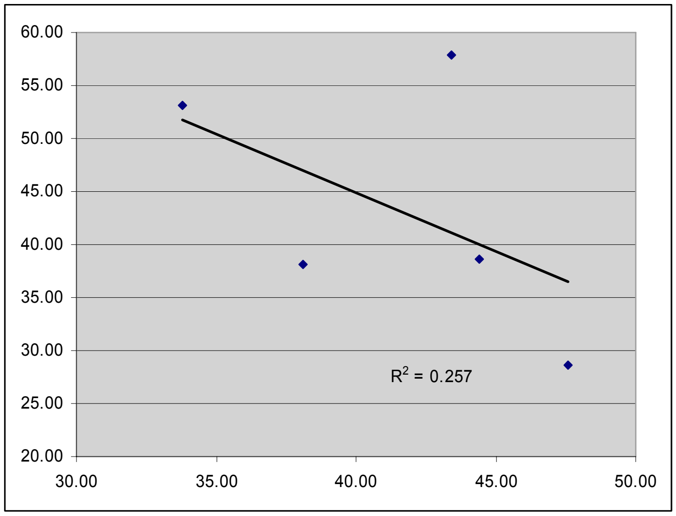


Fig 7.6: Scatter plot of LiDAR intensity (y) and volumetric soil moisture (x) for sample locations shown in figure 7.4.

Finally, selection of sample points relating only to a single discrete location with clear contrast in the LiDAR intensity data, in this case clearly defined ridge and swale and a channel feature (Fig. 7.5) demonstrates a similar negative correlation ($R^2 = -0.25$) between intensity and volumetric soil moisture (Fig. 7.6) although with too few data points to place great significance on this isolated result.

7.1.1 Discussion

Initial examination of these data suggest that factors other than soil moisture play a role in influencing LiDAR intensity and that it is in all probability these unknown factors that most significantly influence variations in LiDAR intensity.

A number of factors may be involved. Ground cover will undoubtedly significantly influence backscattered intensity. Ground cover varies significantly across the Hemington Terrace as the majority of this area is given over to arable agriculture – at the time of the LiDAR flight (February) fields will have been in varying states ranging from bare earth to light spring sown crop and dense brassica. Unfortunately no record of ground cover at the time of the survey flight exists and it is not possible to determine the influence of this factor. The alluvial areas at Hemington are given over to uniform permanent pasture; variations in intensity in the alluvial areas are therefore more likely to represent changes in vegetation due to underlying sediment character rather than differing vegetation *per se*.

Finally, examination of areas of highly contrasting intensity data, that is where it is clear that some characteristic of soil, sediment or ground cover is uniformly affecting intensity, suggest that there is a possibility of a robust relationship between intensity and soil moisture (and probably other factors although these are not considered here). As such it is suggested that in such circumstances at least it should be possible on the basis of careful examination of intensity data to predict areas of wetter sediments.

7.2 Topsoil Moisture, Organic Content and Intensity: Detailed Study

7.2.1 AREA FF

Area FF comprises a part of the Hemmington Terrace (Fig. 7.7) deposits where a minor palaeochannel bisects the terrace. The channel shows as a slight topographical feature, approximately 30m wide and 0.5m deep. The channel is readily apparent in LiDAR elevation and intensity data (Fig. 7.8). The study area is given over to permanent pasture (grassland) and was covered with low closely cropped grass at the time of survey, which took place in November 2006 in dry, clear weather conditions.

Samples for soil organic content and moisture were collected at c 4m intervals over a 40 x 20m area covering the channel and its immediate environment. Samples were processed using the method set out in chapter 3, section 3.10 and sample values used to generate continuous surfaces for visual examination as well as scatter plots.

Fig 7.7: Lockington study area FF, panoramic view showing ground conditions at the time of sample collection.

Topsoil Organic Content varies across the sample area (Figs. 7.9; 7.10; 7.11; 7. 15) such that the outline of the channel feature is clearly evident as variations in topsoil organic content. Overall organic content is low (between 4.5 and 8.9%). Unexpectedly the soils within the channel feature have a lower organic content than those to either side. The scatter plots of LiDAR intensity values and topsoil organic content indicates a slight positive correlation between these two (Fig. 7.10; R^2=0.28) but the point scatter is dispersed and given the low topsoil organic of the channel fill it is hard to derive any definite relationship between intensity and organic content in this instance.

Volumetric Soil Moisture varies across the sample area (Fig. 7.9; 7.12; 7.13; 7.14) widely (from 24-50%) giving a highly heterogeneous continuous surface plot, although with areas of highest soil moisture contained within the channel feature such that its outline is just discernable in the moisture data. The scatter plot of intensity values and topsoil moisture content (Fig. 7.13) indicates a slight negative correlation between these two (R^2=0.016), but with a dispersed point scatter suggesting little confidence can be placed in this relationship.

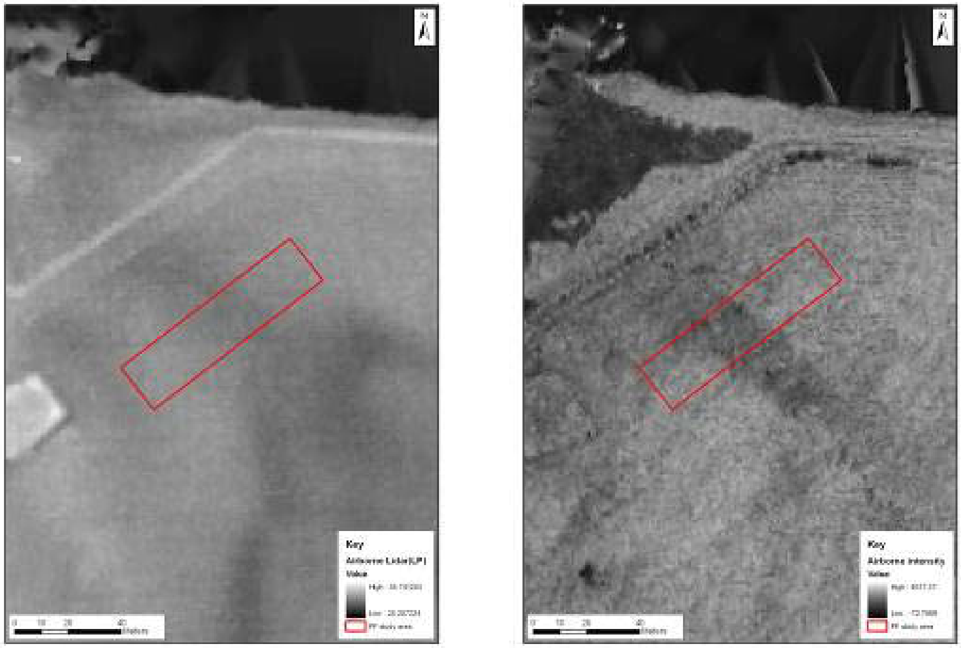


Fig. 7.8: Lockington area FF showing left airborne LiDAR DSM and right airborne LiDAR intensity. The outline of the sample collection area is shown in red.

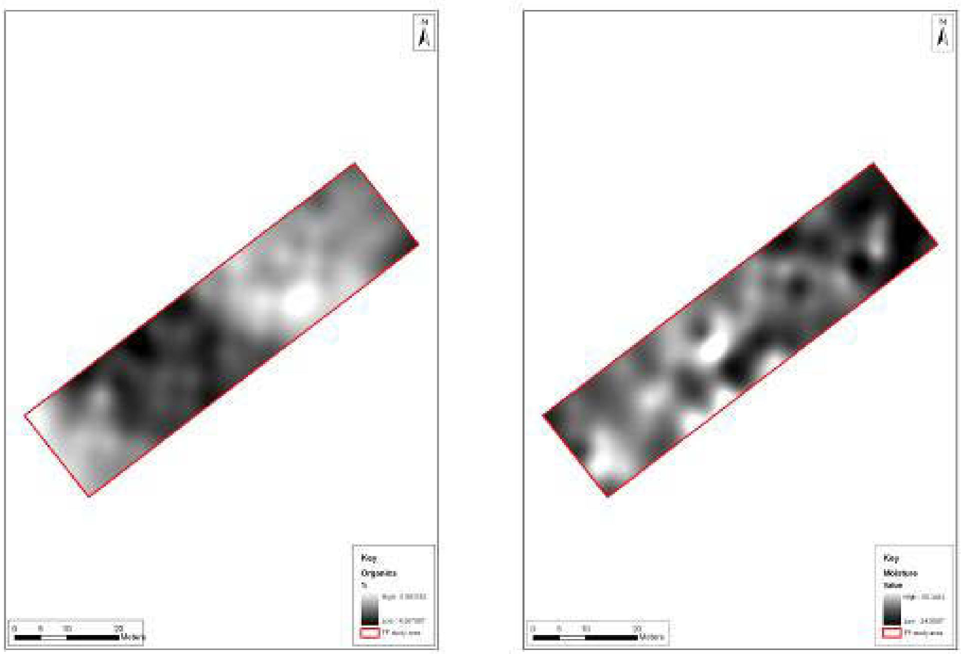


Fig 7.9: Lockington area FF greyscale images showing left topsoil organic content and right volumetric soil moisture of topsoil.

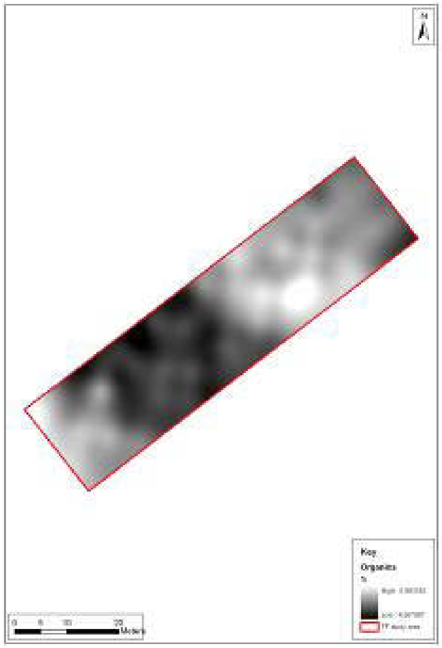


Fig 7.10: Lockington area FF greyscale image showing topsoil organic content.

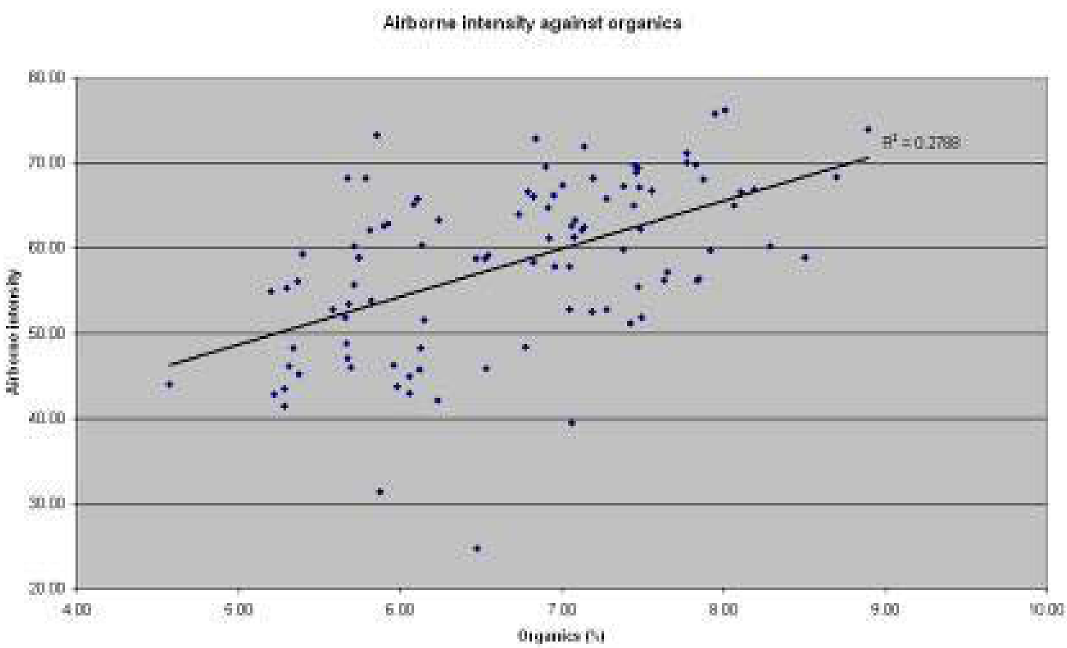


Fig 7.11: Lockington area FF scatter plot showing topsoil organic content (x) and LiDAR intensity (y).

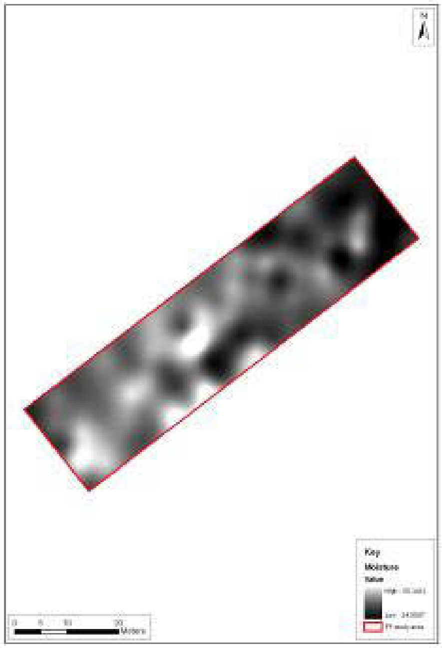


Fig 7.12: Lockington area FF greyscale showing topsoil volumetric soil moisture.

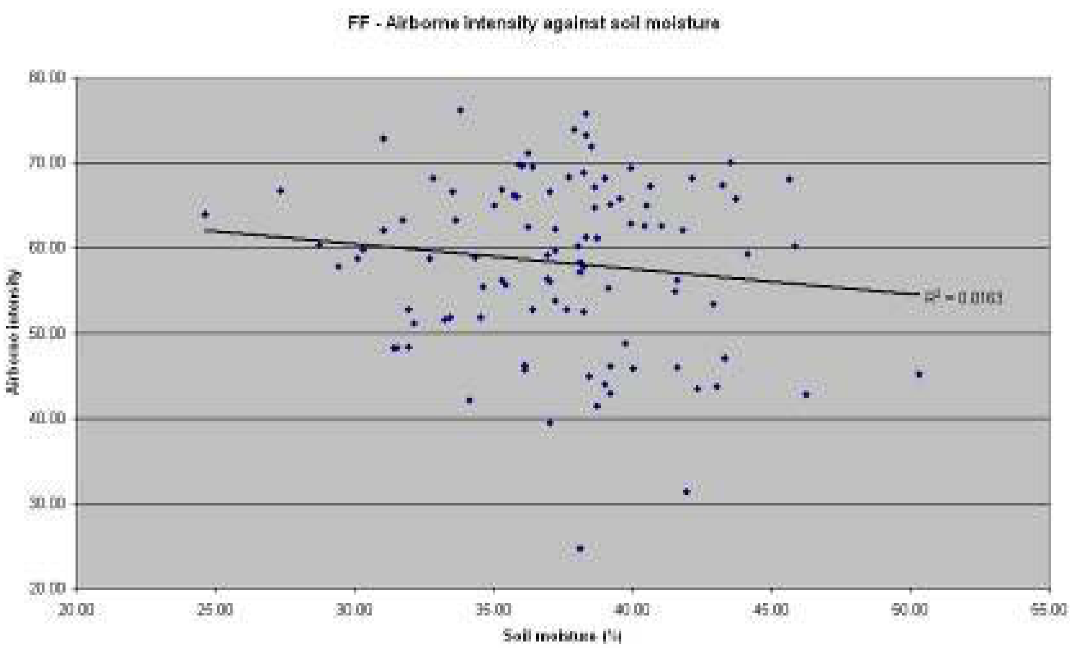
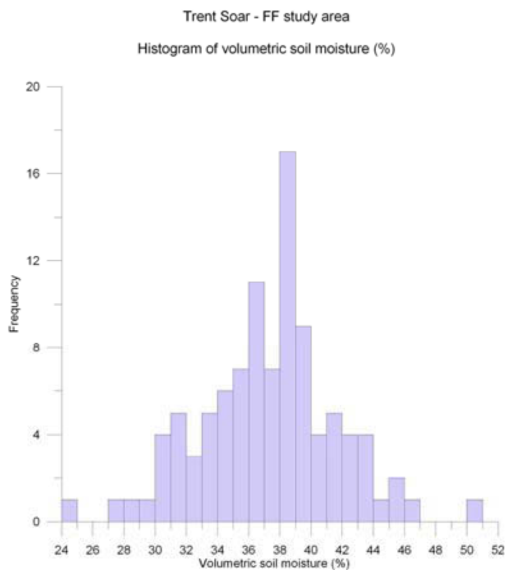
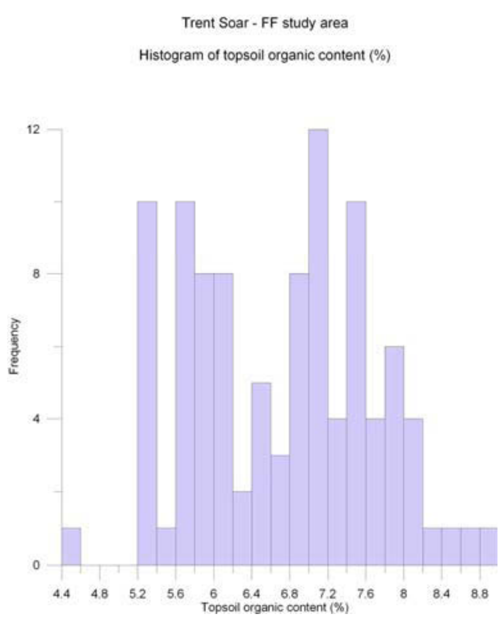


Fig 7.13: Lockington area FF scatter plot showing topsoil volumetric soil moisture (x) and LiDAR intensity (y).



Minimum	24.6
Maximum	50.3
Mean	37.33
Median	37.8
Standard deviation	4.3354889743217
Kurtosis	0.561

Fig 7. 14: L ockington, FF study ar ea, hist ogram of volumetric s oil measurements and summ ary statistics.



Minimum	4.5701
Maximum	8.8897
Mean	6.7051924
Median	6.8277
Standard deviation	0.9452497165429
Kurtosis	-0.859

Fig 7. 15: Lo ckington, F F study ar ea, hist ogram of topsoil or ganic content values and s ummary statistics.

Discussion
Overall results from area FF are disappointing. While both topsoil organic content and moisture display a relationship to LiDAR intensity these relationships are weak and suggest insufficient confidence to allow use of LiDAR intensity as a predictor of these variables. The apparent anomalous nature of the organic content of topsoil in and around the channel requires explanation and undermines any confidence that could be placed in results for this area.

7.2.2 AREA MTF

Area MTF comprises a fragment of the Hemington Terrace deposits at the western edge of a major palaeochannel. Auger survey demonstrated up to 1.5m of channel fill of silty clay alluvium overlying sands above the gravel, while terrace deposits proved to be capped by up to 1.5m of silty clay, perhaps deposited by overbank flooding. The channel shows as a significant topographical feature, up to 75 m wide and 0.7 m deep. The channel is readily apparent in LiDAR elevation data (Fig. 7.16) but is significantly less marked in the intensity data, although the sloping side of the channel feature is clearly defined as a low intensity feature, perhaps due to the effect of topography on the intensity of the reflected laser pulse (pulses reflected from a sloping surface are dispersed over a wider ground footprint and so tend to be of lower intensity; Fig. 7.16). The study area is given over to permanent pasture (grassland) and was covered with low closely cropped grass at the time of survey, which took place in November 2006 in dry, clear weather conditions.

Samples for volumetric soil moisture were collected at c 4m intervals over two 20 x 20m area one (MTF1) focused on the channel and the other (MTF2) the terrace. Samples were processed using the method set out in section chapter 3, section 3.10 and sample values used to generate continuous surfaces for visual examination as well as scatter plots.

Volumetric Soil Moisture varies across the sample area (Figs.7.17 – 7.21) widely , giving a highly heterogeneous continuous surface plot, although again areas of high soil moisture are contained within the channel feature (MTF1 – from 34-45%). The scatter plot of intensity values and topsoil moisture content for MTF1 (Fig. 7.18) is highly dispersed and indicates no significant relationship between these two, however visual inspection suggest that the low intensity values of the sloping terrace edge are reflected in lower soil moisture. The scatter plot of intensity values and topsoil moisture for the terrace feature (MTF2; Fig. 7.19) is also highly dispersed, with no discernable relationship between these two. Interestingly overall soil moisture on the terrace shows little difference to the channel (range 31-50% with both areas showing a mean value of *c*.39%). It is probable that the clay capping of the terrace feature masks any significant contribution to drainage and sediment character caused by underlying coarse-grained terrace material.

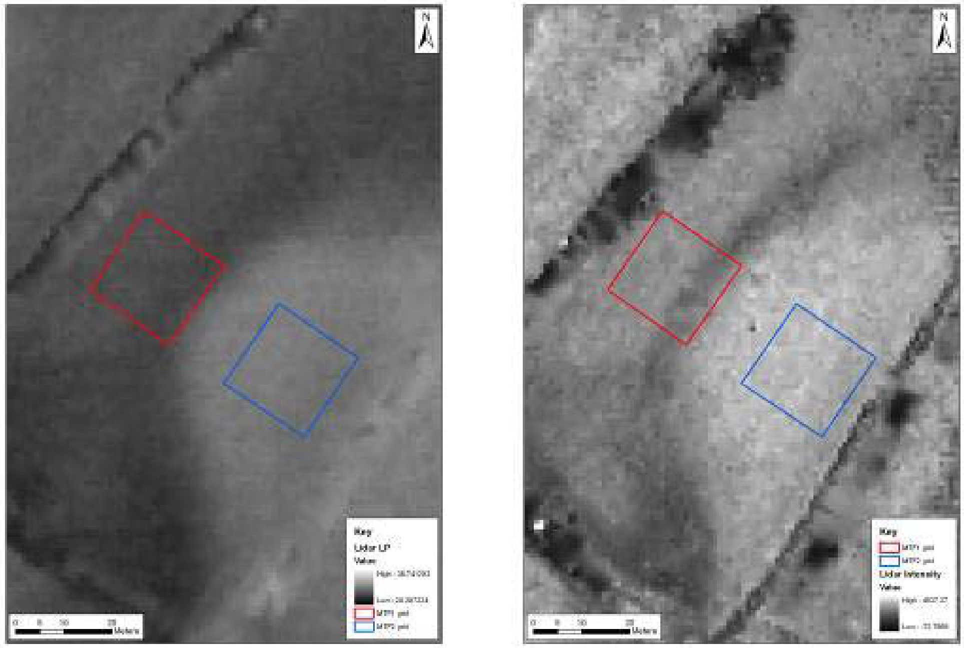


Fig 7.16: Lockington area MTF: Left, LiDAR elevation data and right LiDAR intensity values, red and blue outlines show sample collection areas.

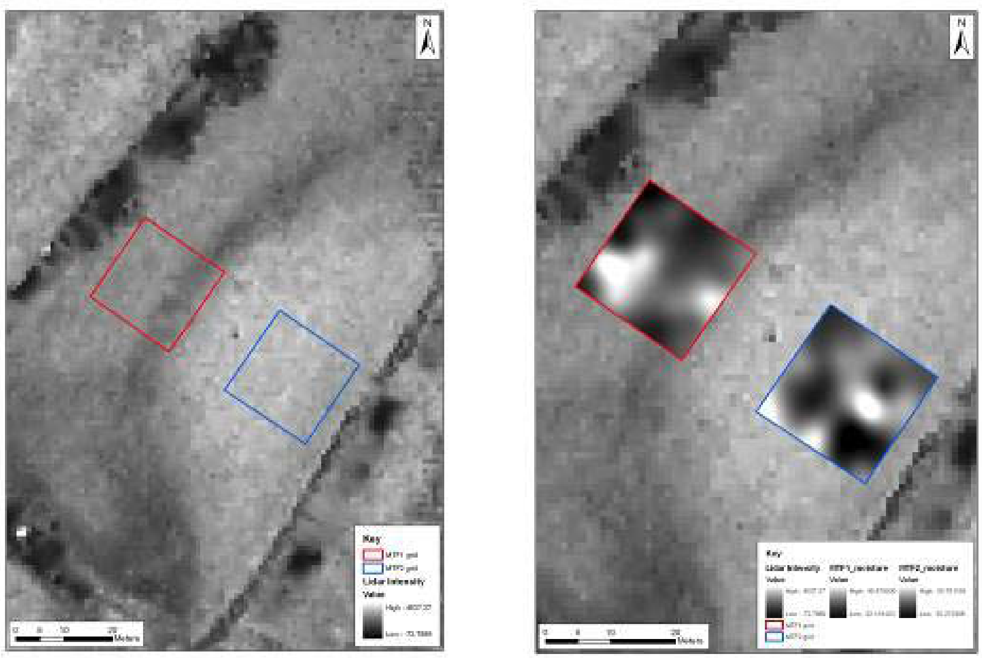


Fig 7.17: Lockington area MTF: Left, LiDAR intensity values and right intensity with greyscale of interpolated volumetric soil moisture for each study area superimposed.

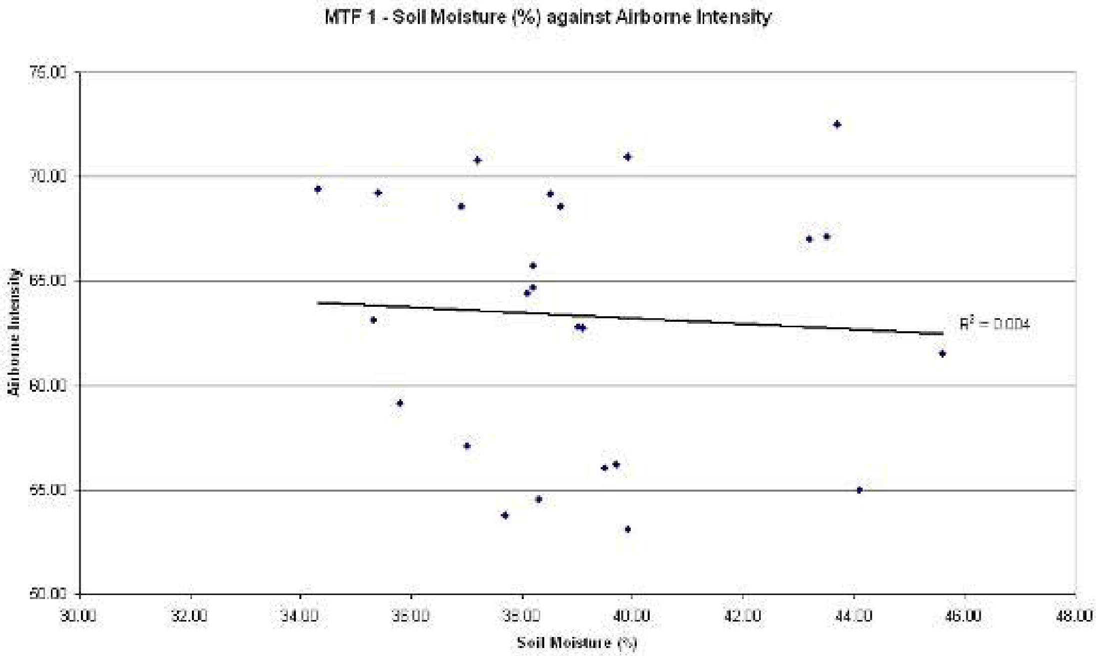


Fig 7.18: Lockington area MTF1: Scatter plot of LiDAR intensity (y) and volumetric soil moisture (x).

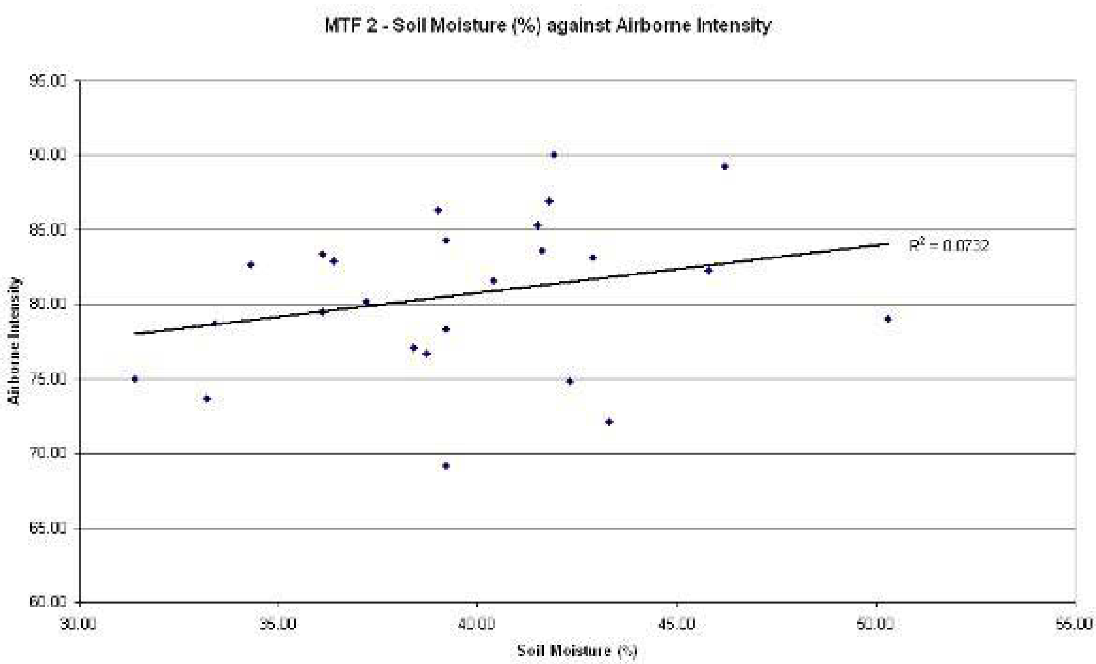
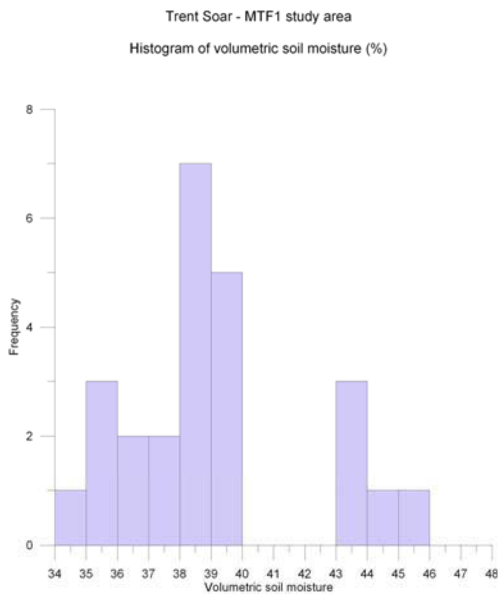
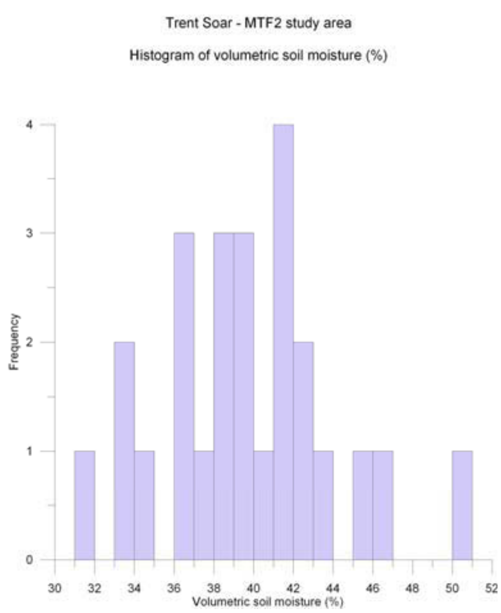


Fig 7.19: Lockington area MTF2: Scatter plot of LiDAR intensity (y) and volumetric soil moisture (x).



Minimum	34.3
Maximum	45.6
Mean	39.072
Median	38.5
Standard deviation	2.9371
Kurtosis	-0.059

Fig 7.20: Lockington MTF1 study area, histogram of volumetric soil moisture values and summary statistics.



Minimum	31.4
Maximum	50.3
Mean	39.592
Median	39.2
Standard deviation	4.402
Kurtosis	0.27

Fig 7.21: Lockington, MTF2 study area, histogram of volumetric soil moisture values and summary statistics.

Discussion
Overall results from area MTF are again disappointing. Topsoil moisture is highly variable and shows no apparent relationship either to geomorphological feature type. This may in part be due to the fact that soil moisture is uniformly high, with little apparent contrast between average soil moisture for the channel feature and the terrace.

7.2.3 AREA MF

Area MF comprises a part of the modern floodplain of the River Trent where a linear channel like feature lies parallel to a raised linear ridge of sand and gravel, probably a channel bar (Fig. 7.22). The channel shows as a slight topographical feature, approximately 20m wide and 0.5m deep the bar as a broader *c*.40m wide *c*.0.4m high feature. Both channel and bar show clearly in LiDAR elevation data, while the channel is slightly apparent in the LiDAR intensity data (Fig. 7.23). The study area is given over to permanent pasture (grass land) and was covered with low closely cropped grass at the time of survey, which took place in July 2006 in exceptionally dry weather conditions. At the time of the survey the linear gravel bar was clearly apparent as a well-defined parchmark in the grass.

Fig 7.22: Lockington panoramic photograph of study area MF at time of sample collection showing channel (left) and bar feature (right).

Samples for soil organic content and moisture were collected at c 4m intervals over a 40 x 20m area covering the channel and adjacent bar. Samples were processed using the method set out in section 3.10 and sample values used to generate continuous surfaces for visual examination as well as scatter plots.

Topsoil Organic Content varies across the sample area from c 5 – c 10.5% (Figs. 7.24; 7.25; 7.26; 7.27) such that the outline of the channel feature and bar are clearly evident as variations in topsoil organic content. Soils within the channel feature have a markedly higher organic content than those associated with the bar feature. The scatter plots of LiDAR intensity values and topsoil organic content indicates a slight negative correlation between these two (Fig 7.26; R^2= -0.06) but the point scatter is dispersed and it is therefore difficult to deduce a definite relationship between intensity and organic content in this instance.

Volumetric Soil Moisture varies across the sample area (Figs. 7.25; 7.28; 7.29; 7.30) widely from 4 – 21%, giving a heterogeneous continuous surface plot within which it remains possible to identify the bar as an area of very dry soils and the channel feature as contrasting and progressively wetter soil. The scatter plot of intensity values and topsoil moisture content indicates no correlation between these two (Fig. 7.28; R^2= -0.005).

Discussion

Overall results from area MF are mixed. Both topsoil organic content and moisture vary markedly in relation to the geomorphological features investigated and these variations are similarly reflected in the LiDAR elevation and intensity data. While there is a slight correlation between LiDAR intensity and soil organic content there is no correlation between LiDAR intensity soil moisture; this in spite of the apparent visual correlation between these two. It should be noted that while the original LiDAR survey was undertaken in February, when the floodplain will have been wet, with some areas showing signs of standing water, the field investigation took place at the height of summer when soils were extremely dry. This discrepancy will undoubtedly have influenced results and may explain the lack of correlation between LiDAR intensity and soil moisture.

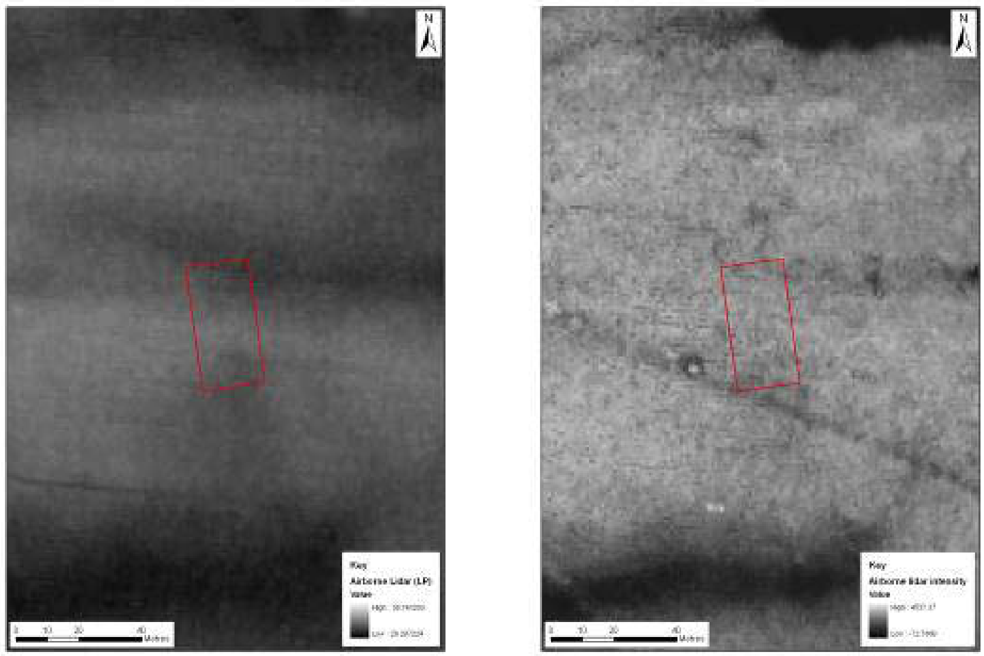


Fig 7.23: Lockington study area MF LiDAR elevation (left) and intensity (right), red outline shows sample collection area.

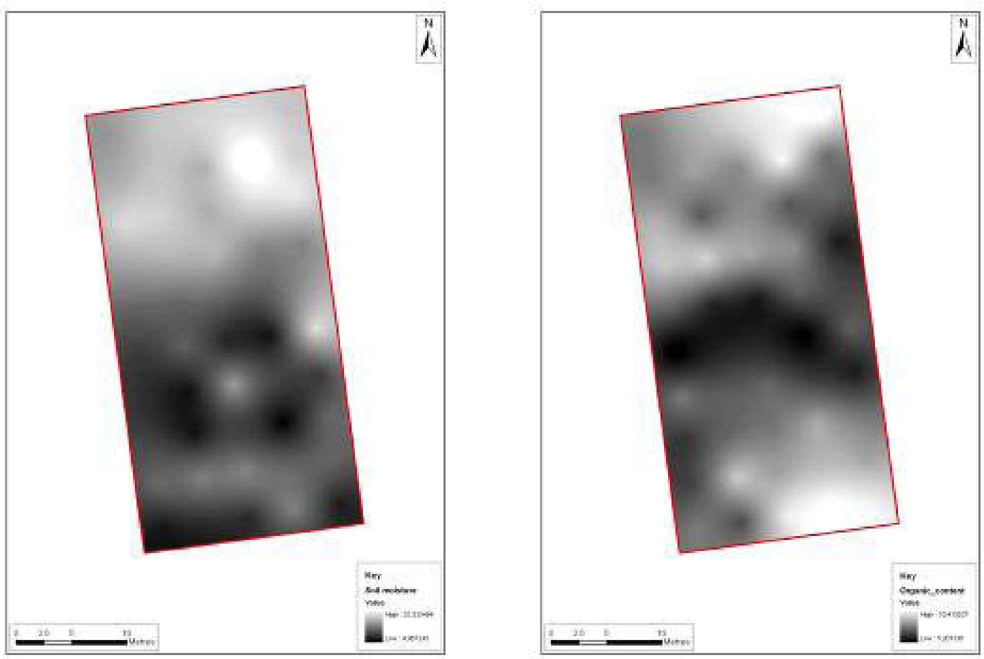


Fig 7.24: Lockington study area MF greyscale images of volumetric soil moisture (left) and topsoil organic content (right).

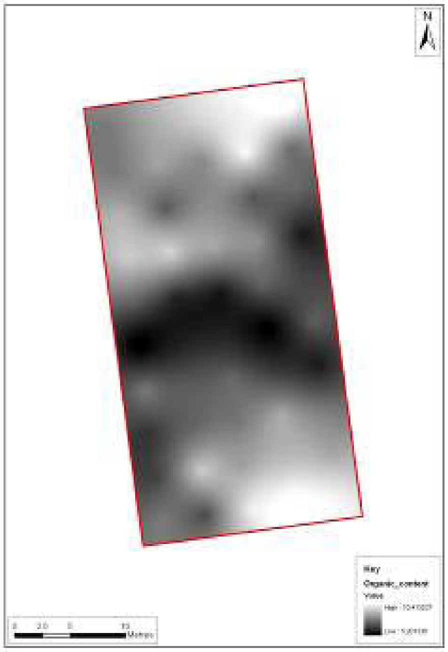


Fig 7.25: Lockington study area MF greyscale image of topsoil organic content.

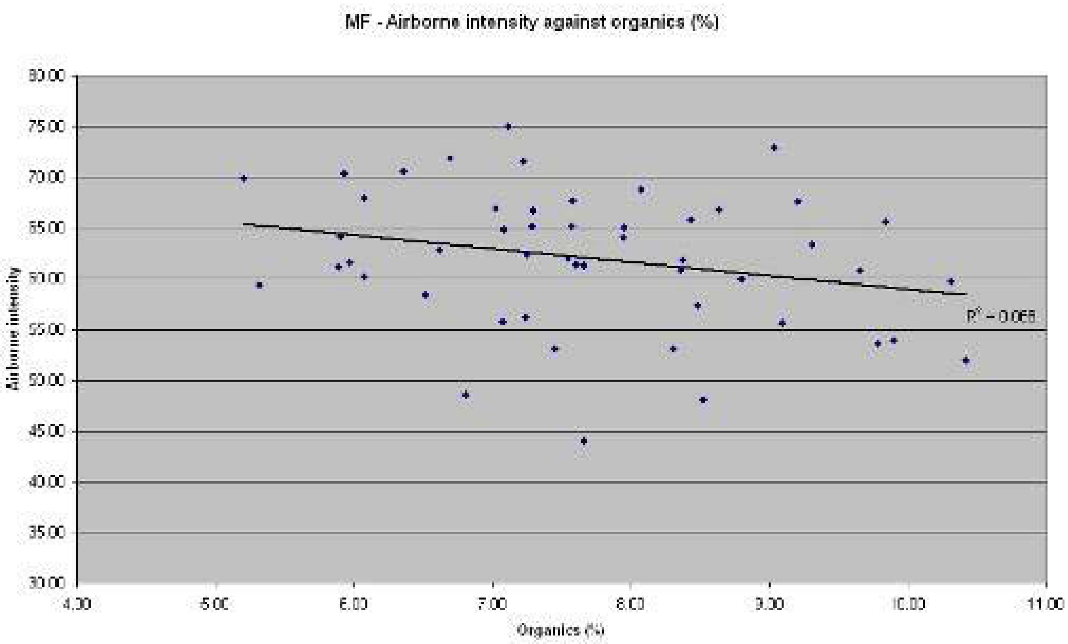


Fig 7.26: Lockington study area MF scatter plot of LiDAR intensity (y) and topsoil organic content (x).

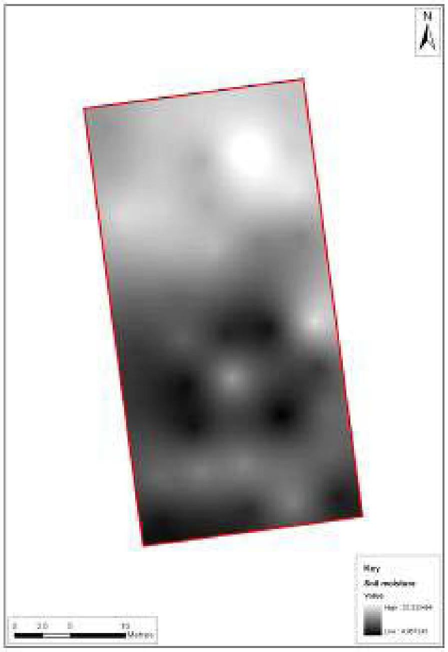


Fig 7.27: Lockington study area MF greyscale image of volumetric soil.

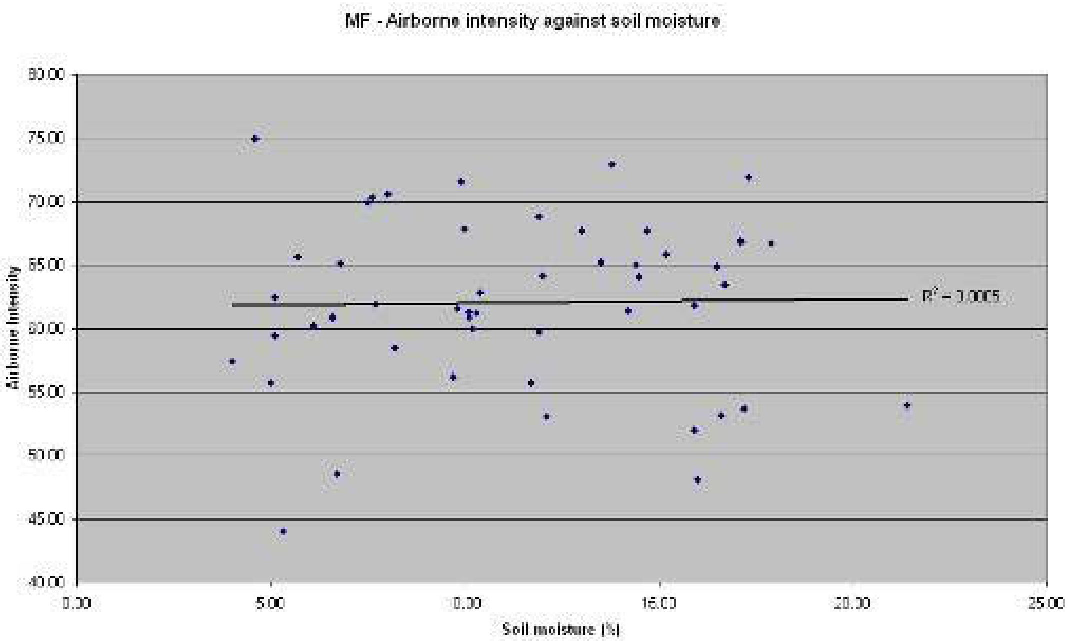
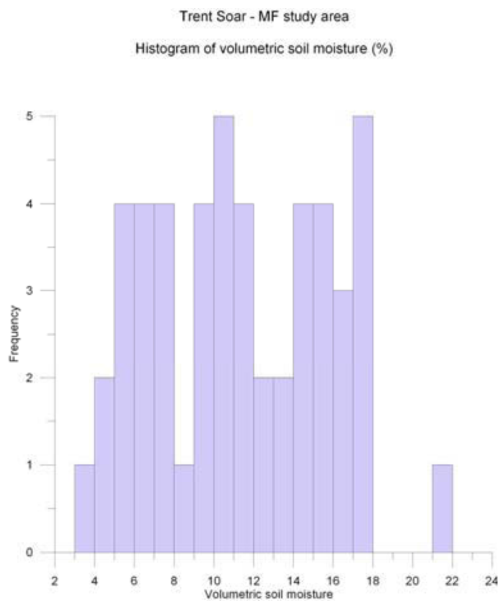
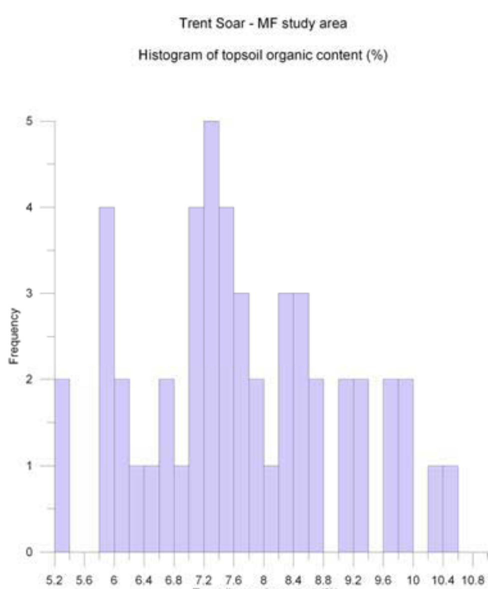


Fig 7.28: Lockington study area MF scatter plot of LiDAR intensity (y) and volumetric soil (x).



Minimum	4
Maximum	21.4
Mean	11.38
Median	11.05
Standard deviation	4.4069981453435
Kurtosis	-0.996

Fig 7.29: Lockinton, MF study area, histogram of volumetric soil moisture values and summary statistics



Minimum	5.20123004913
Maximum	10.413526535
Mean	7.7064081764208
Median	7.57260394096
Standard deviation	1.3129466914432
Kurtosis	-0.594

Fig 7. 30: Loc kington, M F st udy ar ea, hist ogram of topsoil organic c ontent va lues a nd s ummary stastistics

7.3 Conclusions

This study presents a number of problems, an awareness of which must serve to qualify the results achieved to date.

Chief amongst these is the fact that soil moisture and sediment samples for the study areas were not collected simultaneously with the LiDAR flight making the establishment of direct links between sediment character and intensity perilous. To some extent this was overcome by examining the site at several seasons (both summer and late autumn/winter) but ideally contemporary ground based survey is desirable

No ground-covered data exists for the study area for the time of the survey flight. While it is to some extent possible to comment on the influence of ground cover ed based on known patterns of land use and visual interpretation of the intensity data, precise knowledge of crop cover and extent of exposed soil would be beneficial

With these *caveats* in mind a number of conclusions may be drawn. Overall, analysis of LiDAR intensity data in relation to volumetric soil moisture and sediment organic content suggest that no single factor can be clearly associated with variations in intensity.

While there is an apparent (generally negative) correlation between soil moisture and intensity this is too weak to be regarded as significant. A slightly stronger correlation between organic content of soils and intensity is clouded by uncertainly over the meaning of some results (area FF) and the uncertain link between soil organic content and ground cover – since no areas studied were bare soil.

Analysis of small areas of high contrast intensity data suggest that the variations in intensity are reflected in the two sediment characters examined – but crucially the relationship is not fixed and predictable; other unknown factors are clearly at play including vegetation character (green vegetation reflect highly in the NIR and so differences between leaf colour and between vegetated and unvegetated areas will be strong) and sediment coarseness, likely to affect the degree to which the laser pulse is scattered on striking bare soil.

Further more detailed work is required to examine these diverse factors. While further examination of archive LiDAR data such as that for Lockington may prove profitable it is suggested that the greatest advances are to be made in examination of ground based samples collected simultaneously with LiDAR flight data.