IMPROVING POPULATION PREDICTIONS FOR THE SUGARBEET ROOT MAGGOT

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Introduction

Sugarbeet root maggots (SBRM), *Tetanops myopaeformis* (Roder), overwinter as post-diapausing larvae in the soil and then pupate in the spring, emerging as adults in the early summer. It has been demonstrated that high soil moisture prevents successful pupation in SBRM, preventing maggots from turning into adults (see SBREB reports 1998, 1999). Data from 1998 and 1999 indicate that high soil moisture appears to kill the larvae while they are pupating. During pupation, a maggot forms a hard cocoon-like shell (called puparium) within which they metamorphose into adult flies. During this process, considerable physiological changes occur. While feeding on sugarbeet roots, SBRM larvae construct slime tunnels, which are effectively semi-aquatic environments and there may be some respiration directly through the exoskeleton. This is called cuticular respiration and is not uncommon in insect larvae living in aquatic and semi-aquatic environments. However, adult flies live in the terrestrial environment and, like other terrestrial insects, have a series of tubes called trachea inside their body to transport oxygen. Air enters the insect through holes connected to the trachea, which in turn distributes the air throughout the insect's body. If significant cuticular respiration occurs in SBRM larvae, this would have to stop sometime during pupation when they change into adult flies. If soil moistures are very high during the period in the spring when SBRM are pupating into adults, then the developing adults, no longer able to breathe, would drown. The levels of soil moisture required for this to occur would likely only result from standing water. Consequently, low lying areas of production fields may have high enough soil moistures during the insect's pupation period to drown the developing adult fly. This would result in fewer adult SBRM emerging from these low lying areas.

In 1998 we demonstrated the effect of high soil moisture on SBRM pupation in laboratory studies and in 1999 we began the process of examining the relationship of within field topography with the density and distribution of successfully emerging SBRM adults. This information is essential if we are to develop a precision management program for SBRM. In this report we describe the continuation of this research.

We used Geographic Information Systems (GIS) to assess the influence of within field topography on the successful pupation of SBRM. By describing the within field distribution of successfully emerging SBRM adults, placement of monitoring traps could be targeted into areas which would give the most accurate prediction of local adult populations. If we are to develop site specific management tactics for this insect, it is important we know its within field distribution. In addition, we conducted trials in controlled environment chambers to further refine the relationship between soil moisture and the successful pupation of SBRM.

GIS Investigations

Methods - Emerging SBRM adults were monitored in two commercial production fields that had been planted into sugarbeets in 1999 (these fields contained emerging adult SBRM in 2000). One field was located on the University of Minnesota Northwest Research and Outreach Center (NWROC) and the other near Eldred, MN. Both fields had already been topographically mapped using laser topographic equipment, resulting in a detailed series of topographic points within each field (Fig. 1a & 1b). These points were used to interpolate surfaces estimating the continuous topography within each field. We mapped both fields using differentially corrected GPS and the GIS ArcView? . Field boundaries were established and base maps of the fields prepared. The area of each field was then calculated by ArcView; the Eldred site = ~35ac and the NWROC site = ~50ac. Both fields were divided into 1 acre grids and into each grid were randomly placed traps to monitor the emergence of SBRM adults from the soil. We used the topographic maps in ArcView to divide the comparative height in each field into three equal divisions. For example, if the difference between the lowest and highest points in the field was 12 ft, the divisions would be at 4 ft intervals (i.e. 0'-4', 4'-8', 8'-12'). Although the absolute altitudes in the same topographical zone would be different at each of the two sites, it was felt that differentiating high ground from low in one field should be done by comparative height within that field. Wet areas (represented by low zones) in an individual field are a function of drainage far rather than of absolute altitude. A series of monitoring traps were also randomly placed into each of the topographical zones in both fields. This was to obtain a representation of the distribution of emerging adult SBRM based on the topography of the field in addition to the grid placed traps. This design combined a uniform sample design that provided a good estimate of the overall variation within the entire sample area, as well as traps associated with areas that had low or high expected trap catch. This is referred to as a nested uniform stratified sample pattern and is used in spatial investigations of population distributions.

Both soil emergence and sticky stake traps were used to monitor SBRM adult emergence. The emergence traps were essentially black, plastic funnels with a base area of .25m (Fig. 2). The traps were placed wide side down onto the ground and soil piled up the sides of the cone to prevent loss of emerging insects out the side. The tip of each funnel was covered with a modified pill bottle, the cap of which had been cored and covered with mosquito netting to prevent the accumulation of moisture in the bottle. Emergence traps work by containing insects emerging from the soil in the dark funnel. These insects will be attracted to the light coming through the hole at the top of the cone and will either fly or climb up the side of the trap into the bottle. Here they are trapped and can be recovered or counted and released (the SBRM adults recovered in our traps were all collected and preserved in 70% isopropyl alcohol). Our emergence traps were checked at 1-2 day intervals and the number of adult SBRM recovered were counted and totaled. Because the emergence traps are all a standard size, trap catches can be converted to the number of insects per sq. meter. Soil emergence traps were augmented with sticky stake traps. We used orange garden stakes attached to 4' lathing, stakes were attached to lathing with both glue and wood staples at a height of least 2.5' from the ground. Trials were conducted comparing the trap catch from this combination with that of the standard garden stake attached to a shorter 2"x2" post. The sticky stakes were used to evaluate how accurately the emergence traps were operating. If both the soil emergence traps and the sticky stakes showed the same capture pattern, it could be assumed that the emergence traps were a good estimate of the density of SBRM adults entering the breeding population. We found that emergence traps and sticky stake traps both had similar capture patterns although not identical trap catch numbers per location; sticky stake traps always caught higher numbers of adults than did the soil emergence traps. We concluded the emergence trap data was representative of the population at that location.

Traps were monitored from 1 week prior to when emergence was predicted by the emergence model through to 2 weeks after the last emerging fly had been caught in any trap in the field. In this way, we hoped to capture both early and late emerging insects. Soil samples were taken at each trap location and the soil moisture calculated. Trap catches were correlated with soil moisture at each trap location.

The within field distribution of emerging adults at both sites was estimated by interpolating maps from all traps in each field, the geographic coordinates of each trap being obtained with a differentially corrected GPS. These trap locations represent a pattern of points within the field, and associated with each point is the number of adult SBRM emerging as adults per sq. meter. One of the most useful features of GIS is their ability to estimate a value at an unsampled location based on the values of the data points from all of the sampled locations around it. This is called interpolation. We used an inverse distance weighted interpolation method called Kriging. Of the methods available, Kriging provided the best estimates of population distributions from the pattern of point data. We also used the GIS to conduct some point pattern analyses that indicate if certain features (such as low emergence of adult SBRM / m^2) are correlated with geographic feature other than topography (such as slope or aspect). The interpolated surfaces estimating within field topography are geo-rectified, that is there are geographic coordinates associated with every location on the surface. The locations of the sample points were projected onto the topographic surfaces (Fig 3a & 3b) and each sample location, both those in the grid design and those specifically placed into high, medium, and low areas in the field, was categorized as being a high or low area sample point. Based on these two categories, an Analysis of Variance could then be applied to assess if more SBRM adults emerged from high or low areas within fields.

Results - The results from the GIS investigations in 2000 support those of 1999 and lead us to conclude the distribution of emerging SBRM is related to within field topography. It was hoped that the results in both fields sampled in 2000 would provide a stronger relationship between topography and emergence of SBRM adults. Instead, differences between the two fields in the association of emerging SBRM adults and topography provided some interesting contrasts.

In the Eldred field, the interpolated surface estimating topography indicated a slope in the sample area rising from the west to the east (Fig 4a). The kriged surfaces representing emerging adult SBRM showed a distinct gradient in distribution across this slope, with emergence decreasing with the within field topographic height Fig. 4b). In the NWROC field, the interpolated surface indicated the field really had no noticeable slope; rather there were a series of ridges and drainage ditches resulting in the topography appearing corrugated (Fig 5a). Emergence of adult SBRM was quite different in this field (Fig 5b). Although lower levels of adult emergence are noted in some low areas, associations were far less distinct than at the Eldred site or than in either field studied in 1999. It should be noted that the interpolated surface estimating adult emergence is calculated from all of the sample points in the field. Consequently, if there is considerable variation in neighboring points, as there is in this case, the resulting estimate can be misleading. Although there are no distinct patterns associating high numbers of emerging adults with high areas in the field, the ANOVA results indicated there may be an association.

The results of the ANOVA indicated there significantly more SBRM adults emerged from sample points categorized as high areas within the Eldred field than from sample points categorized as low areas ($P=0.017$, Fig 6a). There was no significant difference in the number of emerging SBRM adults from either high or low sample sites in the NWROC field ($P=0.065$, Fig 6b). It is worth noting, however, that the results for the NWROC field are very close to showing statistically more adult SBRM emerging from high area sample points (at a significance level of 0.05).

Laboratory Investigations

Methods - Standard 4” pots were weighed, filled with sifted field soil and re-weighed. Subsamples were taken from the sifted soil, they were weighed, dried in a 110°F for 24 hrs and then weighed again to ascertain the soil moisture by weight. Live, post-diapause SBRM larvae which had been held at 4°C in moistened sand were obtained from the collection at NDSU. These larvae are collected from production fields in the summer and stored below the developmental threshold for SBRM. This causes the larvae to enter diapause, a period of inactivity through which the larvae must pass before they are able to pupate into adults. Eight larvae were buried in the soil in each pot to a depth no greater than 3". The original dry sifted soil contained approximately 2.6% soil moisture by weight. Using the original dry weight of the pot and soil an individual target weight was calculated for each pot at which it would reach a specific soil moisture. Water was slowly added to all pots to increase the soil moisture to reach one of the following regimes: 35%-37%, 37%-39%, 39%-41%, 41%-43%, 43%-45% soil moisture by weight. Soil moistures were to be maintained by weighing each pot daily and adding water until its target weight was reached. The pots were placed in a controlled environment chamber initially set below 8.5°C (the developmental threshold temperature below which SBRM larvae do not develop). The temperature in the chamber was raised daily and the number of accumulated degree-days was recorded. When the accumulated degree-days sufficient to initiate emergence was reached, the pots were allowed to dry and were weighed each day to ascertain the soil moisture. Emerging SBRM adults were to be collected from each pot and the soil moisture at which they emerged was to be recorded. At the end of the experiment, the soil in all of the pots was washed to recover any living or dead SBRM larvae and pupae. Each moisture regime trial was replicated 4 times. An Analysis of Variance (ANOVA) was to have been conducted to ascertain if there was significantly lowered adult SBRM emergence in any of the soil moisture regimes. In addition, an initial trial was conducted to assess the impact of between soil particle size on successful pupation of SBRM. Eight pots were prepared in a similar manner as above, but 4 contained soil obtained with a 4" core sample from a production field on the NWROC and 4 contained 1/2 field soil and 1/2 washed sand by volume. All field soil was sterilized in an autoclave to prevent the introduction of potential insect pathogens. Eight SBRM larvae were placed into each pot and the pots placed into a controlled environment chamber and the same temperature ramping procedure followed as in the previous trials. Soil moistures of >40% by weight were established and maintained in the pots. An ANOVA was to be used to compare the number of emerging SBRM adults from the two soil particle size regimes.

Results - We found it impossible to maintain the soil moistures at 2% ranges. The best we could accomplish was to maintain moisture regimes at approximately 5% ranges. Therefore, the 35% range could be between 32% and 37% soil moisture by weight. We found no significant differences between regimes targeted at 39%-41%, 41%-43% and 43%-45%. In addition, we found no significant difference in the soil moisture regimes of 35%-37%, and 37%-39%. Because of the difficulties in maintaining the soil moistures, there was considerable overlap of soil moisture in the 35%-39% regimes and the 39%-45% regimes. There were significantly fewer SBRM adults emerging from the 43%-45% moisture regime than from the 35%-37% moisture regime. This simply supports our previous data. Unfortunately, using these methods, it is probably impossible to more clearly define the points where soil moisture impacts SBRM pupation. This may not be important as it appears the soil moistures have to be at or near saturation for there to be a significant impact on SBRM pupation. It may be that SBRM pupation is only affected in those areas of the field which are flooded during their pupation.

It was decided to assess the effect of saturated soils of different particle size on the pupation of SBRM. By adding the same amount of water to the field soil and the sandy soil, the latter simply drained out more efficiently and the trial resulted in different soil moistures (a trial already conducted last year). In the field, this would simply mean that with similar precipitation, SBRM pupae in sandier soils are not exposed to high soil moistures for as long as those in less-well drained soils. Therefore, we decided to maintain both soils at saturation, obviously requiring water being added more frequently to the sand mixture than the field soil. No adult SBRM emerged from either soil mixture, leading us to suspect that regardless of soil type, if soil moisture is at saturation, SBRM pupal mortality will occur.

Summary

Although there is an association between field topography and SBRM adult emergence, it may not be possible to incorporate this into the emergence model. It appears that the relationship is a distinct threshold rather than a continuous response with steadily decreasing emergence. However, this relationship does have value from a spatial viewpoint. We now know from where within last year's beet fields the highest emergence of adult flies is likely to occur. This information can be used to enhance current monitoring efforts by targeting traps within last year's fields to get a more accurate estimate of the current year's adult SBRM population. IN addition, if targeted management is to be developed, the spatio-temporal distribution of all stages of SBRM will be needed.

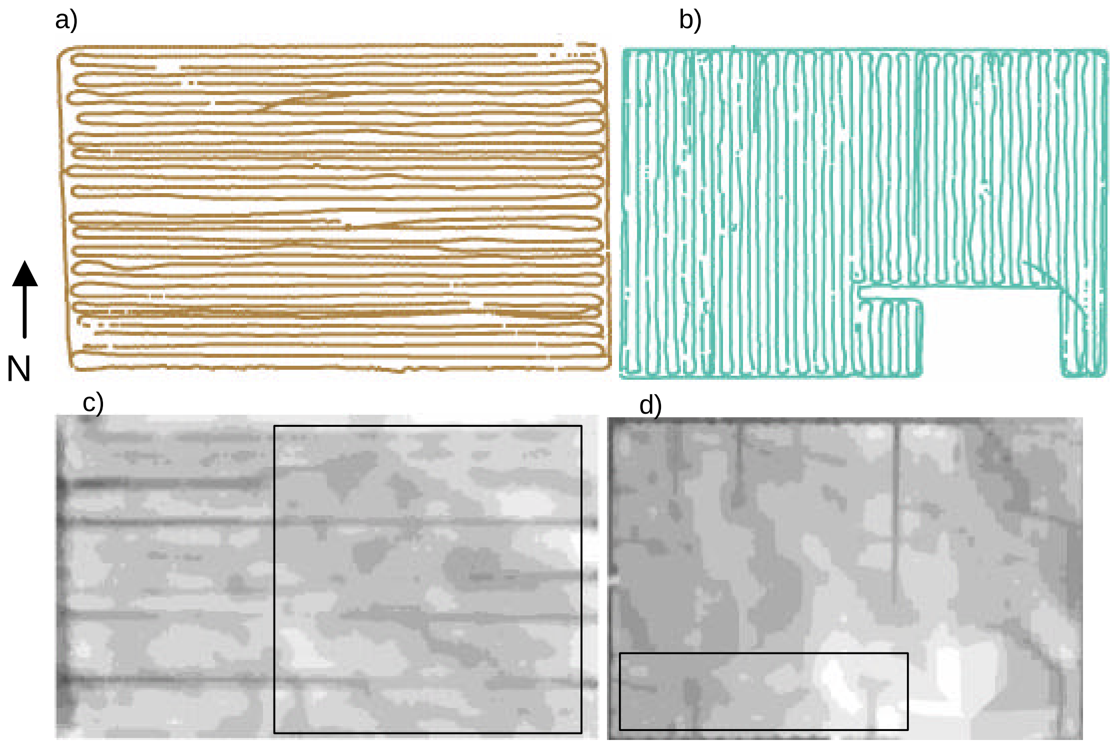


Figure 1. Points obtained by laser topography from both fields. These points are used to interpolate a response surface that estimates the topography of the entire field (the lower two maps). The Eldred and NWROC fields are not represented at the same scale.

a) Points from NWROC field.
b) Points from Eldred field.
c) Interpolated surface estimating within field topography for NWROC field. Increasingly darker shading represents increasingly lower areas in the field. The line box indicates the study area (~50 ac).
d) Interpolated surface estimating within field topography for Eldred field. Increasingly darker shading represents increasingly lower areas in the field. The line box indicates the study area (~35 ac).

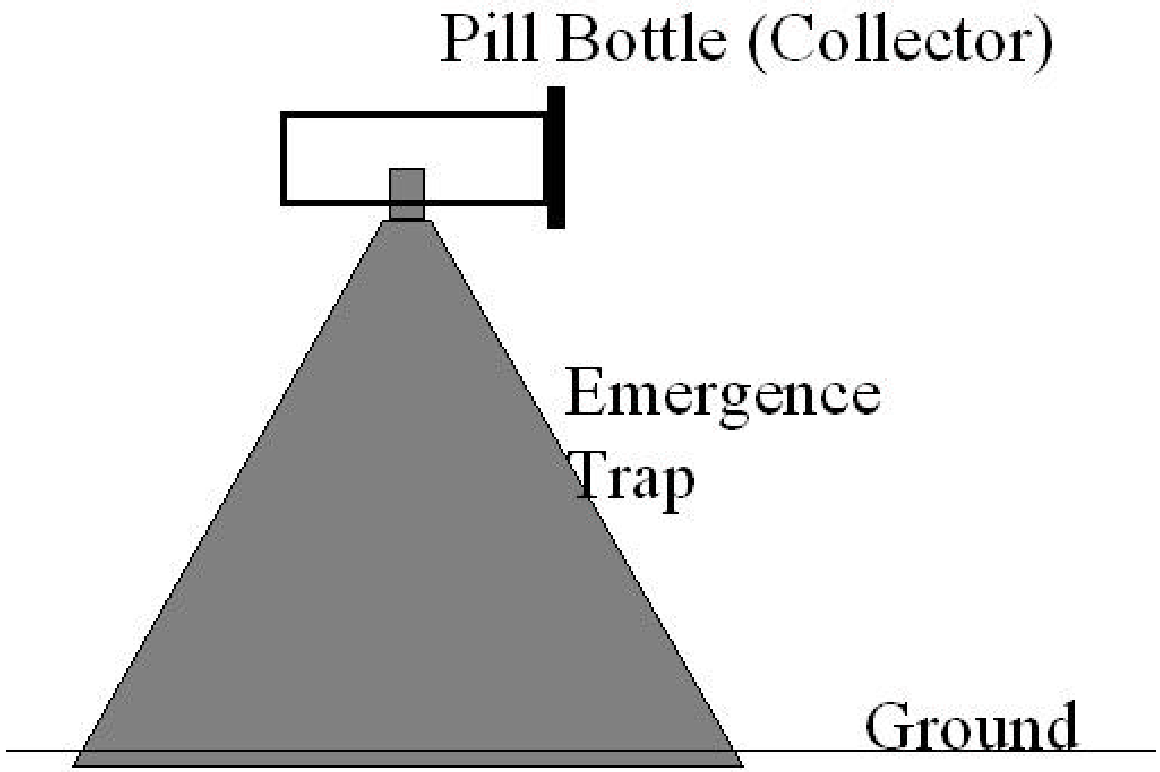


Figure 2. Emergence trap designed to capture adult insects emerging from soil. The bottom of the cone is buried beneath the ground level and emerging insects are attracted to upper tip of the cone, the only light available, where they become trapped in the pill bottle.

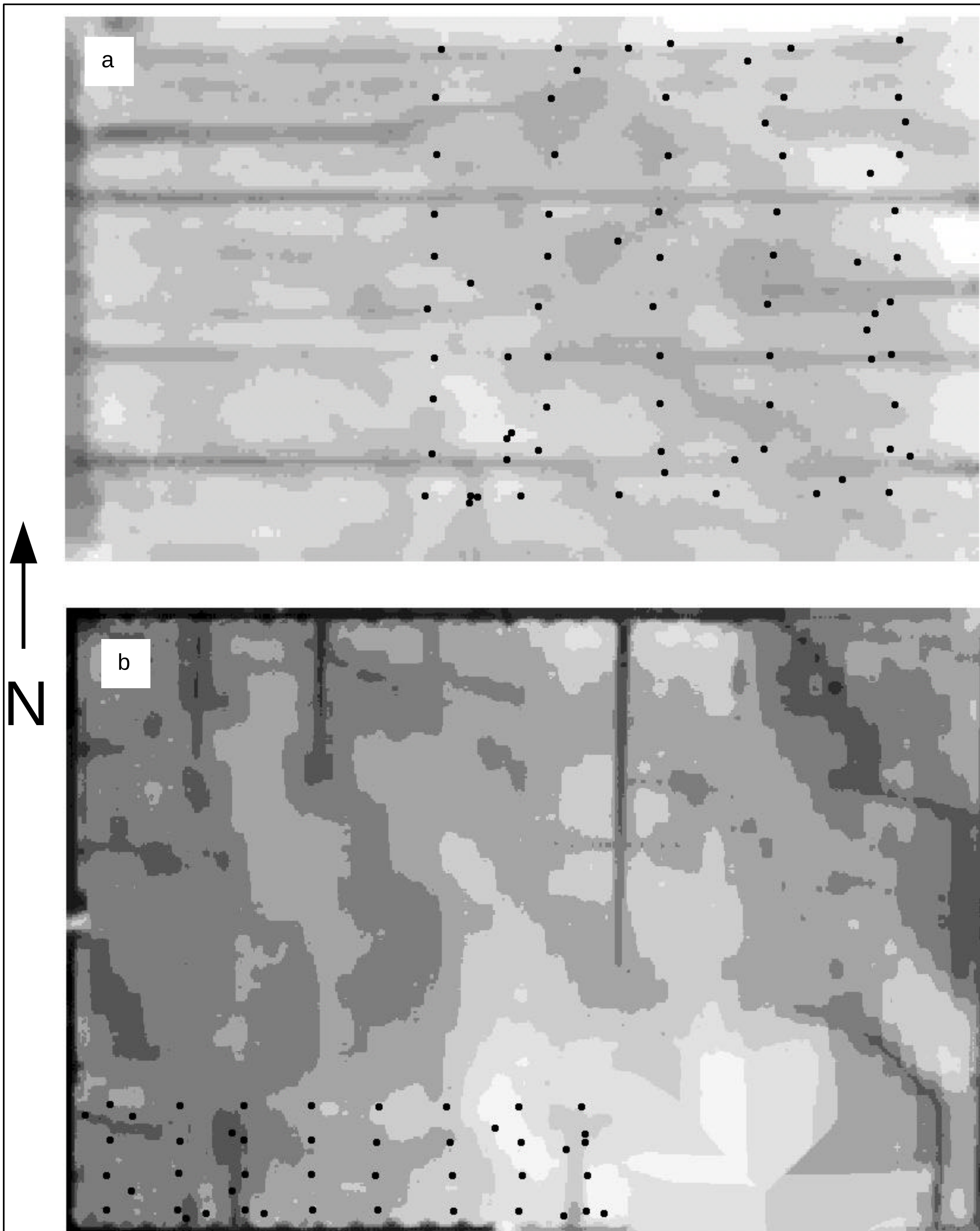


Figure 3. Interpolated surfaces estimating topography in NWROC field (3a) and Eldred field (3b). Increasingly darker areas represent increasingly lower areas within the fields. Dark dots represent sample locations within each field.

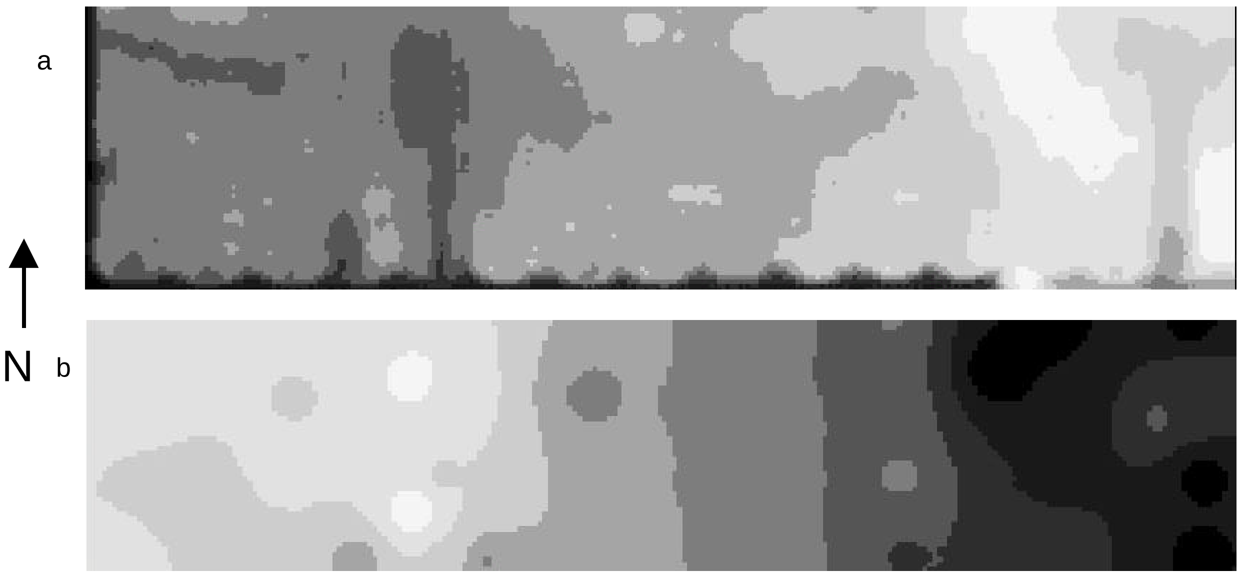


Figure 4. Interpolated surfaces for Eldred field. The association of topography and adult emergence is clearly demonstrated by the gradient of topography and that of emerging adult SBRM.

4a) Interpolated surface estimating topography in study area of Eldred field. Increasing darker shades represent increasingly lower areas within the field. Note the slope; shading of the map is dark at the west side and lightens as it progresses to the eastern margin of the study area. Low lying areas in the west end of the study area rise to higher areas on the eastern side.

4b) Interpolated surface estimating the emergence of SBRM adults from the study area within the Eldred field. Increasingly darker colors represent increasing numbers of emerging adult SBRM. Note the distribution gradient of emerging adults within the study area; the darker colors in the east, epresenting high populations of emerging adults, changing to lighter colors in the west, representing low populations of emerging adults.

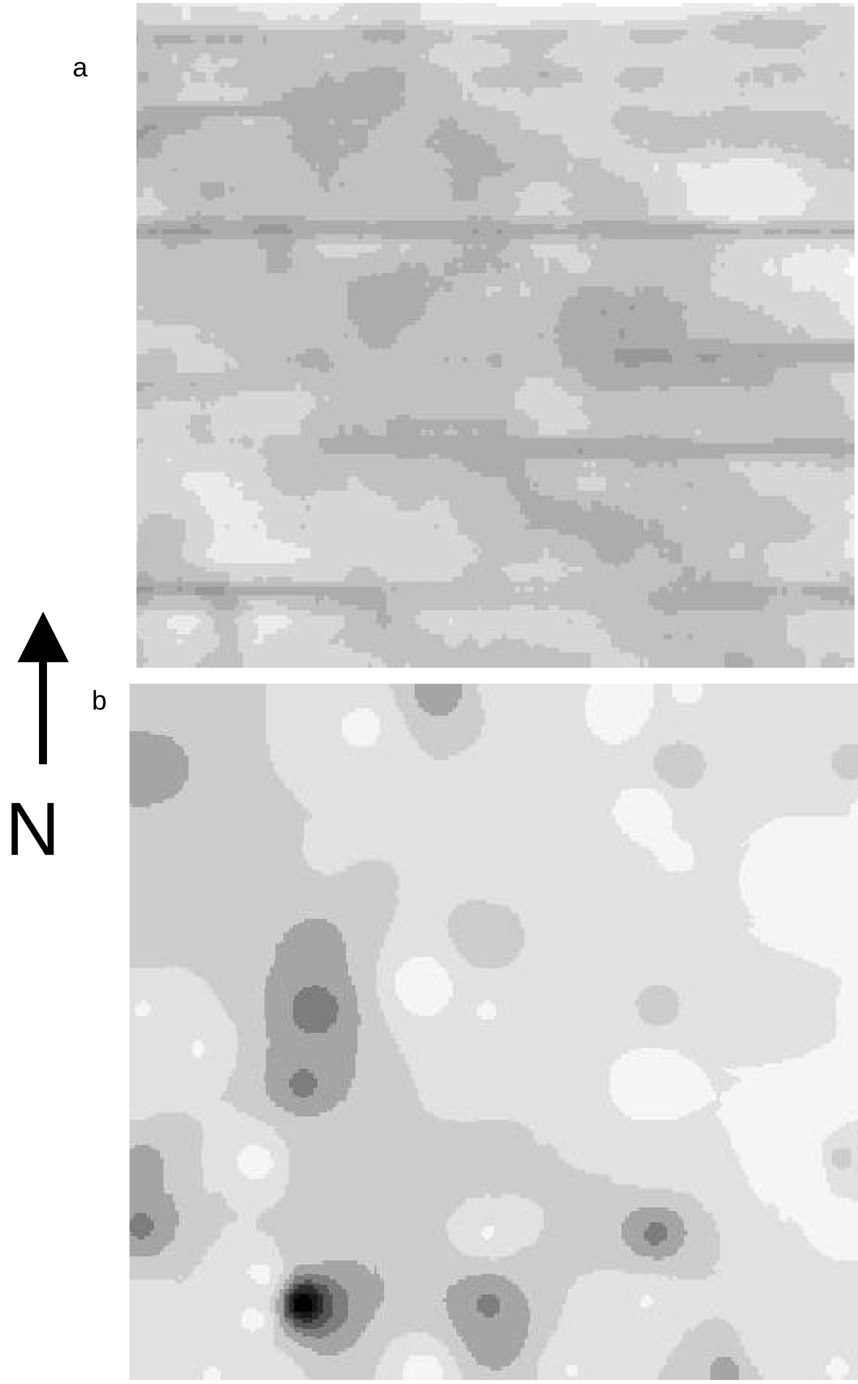
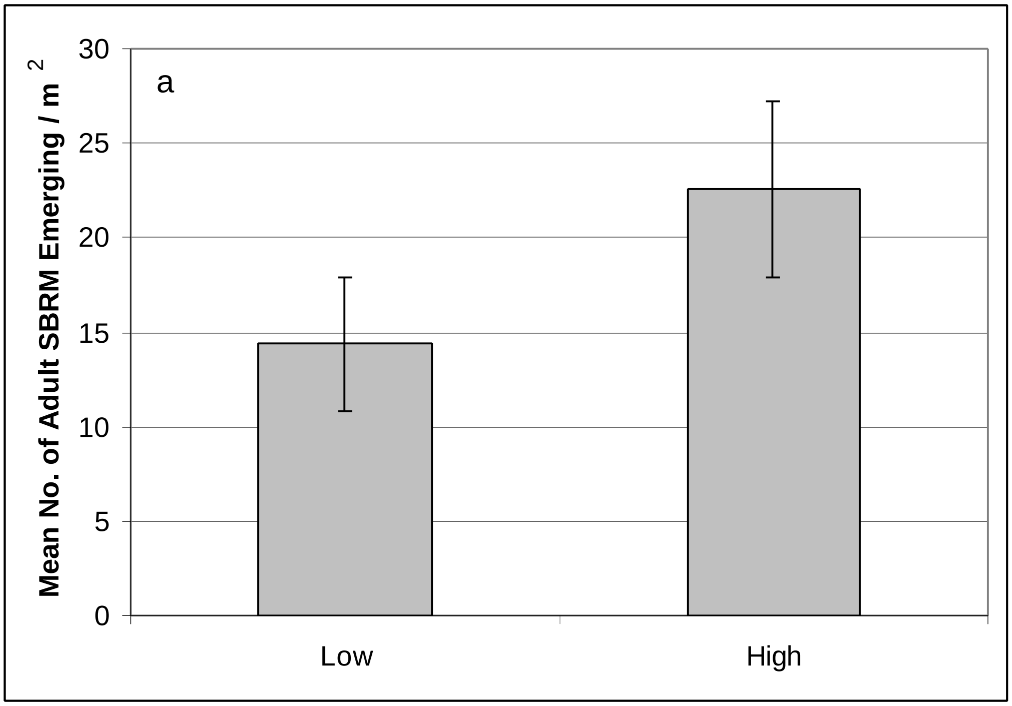


Figure 5. Interpolated surfaces for NWROC field. The association of topography and adult emergence is clearly demonstrated by the gradient of topography and that of emerging adult SBRM.

5a) Interpolated surface estimating topography in study area of NWROC field. Increasing darker shades represent increasingly lower areas within the field. Note the ridge like appearance of the topography.

5b) Interpolated surface estimating the emergence of SBRM adults from the study area within the NWROC field. Increasingly darker colors represent increasing numbers of emerging adult SBRM. There are some areas wherein higher numbers of emerging adult SBRM correspond with higher areas within the field, however, no strong pattern of association appears.



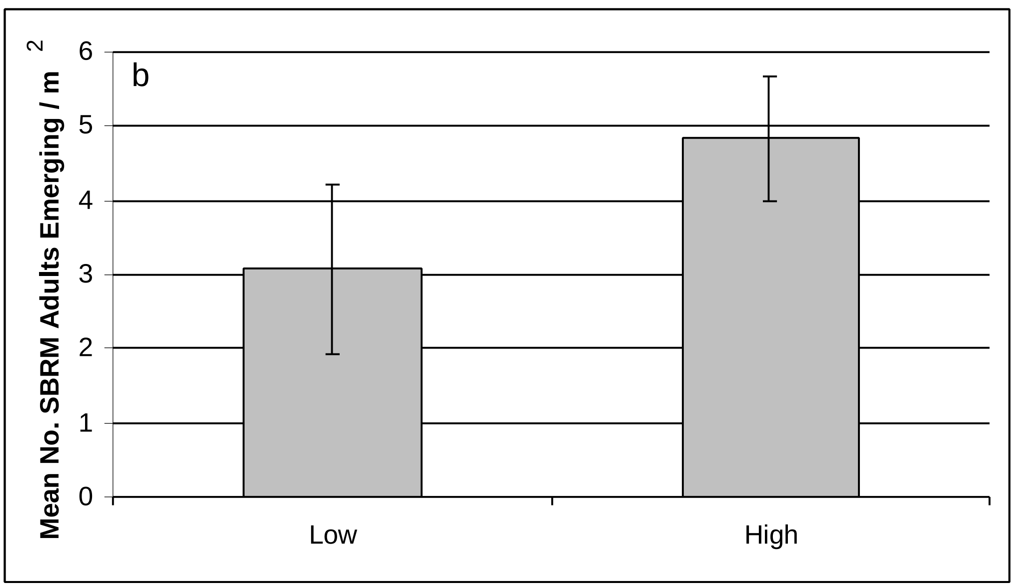


Figure 6. Mean number of emerging SBRM adults as measured by traps categorized as being in high or low areas of both fields. Vertical bars represent 95% Confidence Intervals.

6a) Mean number of SBRM adults emerging at sample points in the Eldred field.
6b) Mean number of SBRM adults emerging at sample points in the NWROC field.