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Spatial Productivity Analysis of Tropical Apple (*Malus sylvestris* Mill) in Relation to Temperature with PCRaster

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Abstract: Temperature is the major factor limiting the cultivation of apple (*Malus sylvestris* Mill), a subtropical species, in the tropics. This fruit crop, successfully cultivated at high altitudes in the region of Malang (East Java, Indonesia), showed a decline in productivity (fruit yield and quality) in the last decade. A series of studies were conducted in the production centre of apple in the region of Malang to investigate several environmental factors evoking the decrease in the productivity of apple trees (cv. Manalagi) in 2008-2009. The present paper was focused on the analysis of air temperature as a limiting factor of the productivity of apple trees. Data of apple productivity were recorded at the first harvest of 36 apple orchards of 9-35 years old selected randomly that covered the whole range of orchard altitudes (861-1,434 m) in the study area. Air temperature and relative humidity during the day (0.06, 12.00 and 18.00n h) were recorded at the orchard locations. The air temperature, closely related to the altitude, declined at a rate of 0.679 °C 100 m^{-1} of altitude close to a wet lapse rate. A high variation was found in the relationship between temperature and productivity which showed, on average, a tendency to decline with an increase in the temperature. Spatial distribution maps (fruit yield and quality) were generated with PCRaster software. The maps were used to regenerate the relationship between the temperature and the apple productivity over the whole area of apple production center.

Key words: Tropical apple (*Malus sylvestris* Mill), temperature, spatial analysis, PCRaster.

1. Introduction

Apple (*Malus sylvestris* Mill), a subtropical species by origin, is successfully cultivated in Malang, Indonesia at a commercial level. The cultivation of apple trees in Malang reached a golden period between 1970s and 1990s with a total area of apple orchards around 2,000 ha. This has contributed significantly to the economy of community particularly in Nongkojajar and Batu which are the main regions of apple orchards situated successively in the Northeast and Northwest of Malang. Thereafter, notably after the monetary crisis in 1997 in Indonesia, the production of apple from Malang areas declined. In one of production centers (Batu region), for instance, the rate of reduction in a period of 2002-2004 was estimated to reach 60% due mainly to a reduction in the productivity of trees or fruit yield per tree [1]. The average of productivity in 2004 (17.64 kg $tree^{-1}$) declined sharply to around 50% of that found in 2002 (34.93 kg $tree^{-1}$). A reduction in the population of trees during the same period also occurred at a rate of 16% possibly as a consequence of reduction in the productivity of apple trees.

It is considered that the existence of apple orchards in Malang is of great importance due to its role in the economy of farmers in the region. In particular, it has been a uniqueness of Malang, the second major city after Surabaya (the capital city) in the province of East Java, which has received considerable attention from

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other tropical countries (e.g., the Philippines and Kenya). It may be important to state in brief the story of apple cultivation in Indonesia which was started with a trial of 17 cultivars (each of 5 grafted seedlings) including cv. Manalagi (probably Zoete Armgaard) at Cipanas (700 m asl.), West Java in 1950s. The apple seedlings were obtained from Australia as told by Mr. Widodo (private communication) who is regarded as one of considerable merit in the development of apple in Malang. A trial of apple cultivation in Malang was initiated at Tlekung (> 800 m asl.) in 1956 which was concomitant with the appointment of Mr. Widodo as the head of Horticulture Research Institute in Malang. In 1958, the cultivation of apple was also introduced to East Nusa Tenggara and South Sulawesi. The vegetative growth of all planted apple trees was excellent, but the trees failed to flower after several years with a general management of trees as applied to other crops (fertilizer use, irrigation, etc.). Experiments conducted in 1960 with fertilizers and irrigation as treatments also failed to promote flowering. It was then found accidentally that tree pruning, aimed initially at reducing the dense shoot growth of some trees, was able to promote flowering. After several studies, defoliation (total leaf removal) was found to be the main key to the success of apple flowering in Malang. The success of apple trees to produce fruits in Indonesia was first reported in 1963 in a seminar.

In the maintenance of apple existence in Malang, a study initiated by the local government (Batu) in a program of Local Economic Resource Development (LERD) was carried out to find factors responsible for the decrease in the apple production in the region of Batu in particular. The study led to a conclusion that a decrease in the apple productivity was associated with degradation in soil fertility [2]. A decrease in soil organic matter was considered to be a major problem due to an increase in the rate of erosion as a consequence of increasing local deforestation. The high-input management of apple orchards with a heavy use of chemicals, leading to an accumulation of chemical residues in the soil, was also considered as an important factor of the soil fertility degradation. However, data from field observation such as soil nutrient status were not available to support the conclusion.

Other factor of great interest is temperature due to global warming (climate change) and the prominent role of temperature on the growth and development of apple trees characterized by a chilling requirement for dormancy process leading to flower development [3, 4]. The annual growth cycle of apple (*Malus domestica* Borkh.) with the phase of dormancy and shoot growth including phases from flower induction to fruit development is strongly dependent upon temperature [4]. The effect of climate change on agriculture including apple production has received considerable attention [4-6]. A decrease in the productivity of apple crop resulting from an increase in temperature due to global warming (climate change) was reported in Himachal Pradesh, India [7]. Chilling unit declined with years (1986-2004) for the attitude range of 1,221-2,400 m asl., but increased at 2,700 m asl.. This means that the suitability of areas for apple cultivation declined at lower attitudes (1,221-2,400 m asl.). The chilling unit was calculated with the Utah model [8].

Although apple varieties cultivated in Malang has adapted to the local condition without a normal chilling requirement, the apple trees produced fruits only at altitudes above a certain limit. Normally, a temperature of < 7 °C for at least 300 h is required to completely release dormancy for varieties of low-chill apples [9]. Insufficient chilling leads to delayed foliation, and reduced fruit yield and fruit quality. This implies that temperature is a major factor limiting the success of apple cultivation. Dorsett Golden, a low chill type of apple, was observed at the University of Florida to grow as an evergreen, just like apple in Malang without a dormant period or chilling requirement, but the trees did not fruit properly [10]. At the initial development of apple in

Indonesia, the lowest altitude recommended for the cultivation of apple is 700 m asl.. At present, however, many apple orchards at low altitudes were replaced by other crops due to the low productivity of the apple orchards. The present study was aimed at examining the productivity of apple in Malang in relation to air temperature.

2. Materials and Methods

2.1 Data Collection

A series of field surveys were conducted for three years (in 2007-2009) in the region of Batu (7°52′S & 112°31′E), one of the main regions of apple orchards, about 20 km to the northwest of Malang, East Java, Indonesia. The apple orchards are spread out on the slope (mountainside) of Mount Kawi in the Southwest, Anjasmoro in the Northwest and Arjuno in the Northeast (Fig. 1). The orchards on the North-facing slope of Mt. Kawi (North aspect) may receive less light than those on the Southeast aspect and Southwest aspect do. Tlekung, where the first apple orchard was initiated in Malang in 1956, was located on the North aspect about 5 km to the South of Batu City.

The field surveys were focused on apple var. Manalagi (*Zoete Ermgaard* variety, possibly), which is the most widely cultivated and famous one. On each aspect (North, Southeast and Southwest), 12 orchards of different altitudes were selected randomly from the existing orchards owned by cooperative farmers with a total of 36 sites of observation (Fig. 1). The geographic position of each observation site was recorded with a GPS (Geographics Positioning System, Garmin V), and the age of trees (orchards) was also recorded on the basis of farmers' information.

The main observations made in the field in the first year of study (2007) consisted of tree productivity and fruit quality. Supporting observations made consisted of the growth of trees (tree height, canopy height, canopy diameter, stem diameter and number of branches), temperature and humidity. Temperature Hygrometer (TA218C, Shenzhen Liweihui and

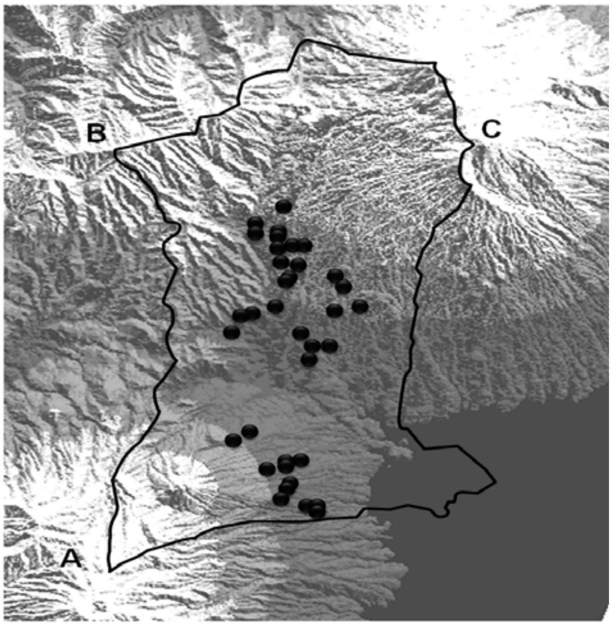


Fig. 1 The region of Batu surrounded by three mountains (A = Mt. Kawi, B = Mt. Anjasmoro, and C = Mt. Arjuna). The closed circles in the figure were the study sites (apple orchards).

relative humidity at each site (apple orchard location) were measured with a digital Thermo & Technology Co., Ltd.) at 06.00, 12.00 and 18.00 for three consecutive days. The productivity of trees (fresh weight of fruits per tree) from randomly selected 10 trees at each site was recorded at harvest in cooperation with the farmers (owners). The weight of Graded-A, B & C fruits (high, moderate and low quality), based mainly on fruit size and complexion, was also recorded. The selection of fruits for a particular grade was undertaken by the farmers.

Other fruit qualities (fruit diameter, weight/fruit, sugar content and firmness) from each orchard were measured on 10 fruits taken randomly. The diameter and weight of fruits were measured with a caliper and weighing, respectively. The sugar content was measured with a hand refractometer (Q.C.-Master Refractometer, Atago), and fruit firmness with a pnetrometer (Wagner, Force Dial FDK 30). Other observations made in the first year of study, but not reported in the present paper, included the management types of orchards (based on interview), infiltration and nutrient (N, P & K) content of either the soil or tree leaves.

2.2 Data Analysis

In addition to basic analysis, data (fruit yield and quality) were analyzed spatially to generate the distribution map of fruit yield and quality over the landscape under study that were used to establish the relationship between fruit yield or fruit quality and altitude (temperature). The spatial analysis was executed with PCRaster, a raster-based type of GIS (geographical information system) consisting of the modules for Cartographic, Dynamic and Geostatistical Modelling [11, 12]. The PCRaster software, designed to develop and deploy spatio-temporal environmental models, has been used for the spatial modeling of various environmental cases [13-15]. Topographic map or DEM (digital elevation map) of the region under study, required in the spatial analysis, was acquired from Bakosurtanal (The Indonesian Coordinating Agency for Surveys and Mapping) or BIG Geospatial Information Agency with a resolution of 30 m × 30 m).

The fundamental step in the analysis is to find the best variogram model, the equation of semivariance [$\gamma(h)$] as a function of distance (h). Microsoft excel was used at first to explore the best model and the value of model parameters. The model was then used and evaluated in the Geostatistical Modelling of PCRaster to produce spatial distribution of fruit yield and quality of apple trees in the region under study. An average of fruit yield and quality in a particular range of altitude was regenerated with the cartographic modelling of PCRaster.

3. Results and Discussion

3.1 Tree Growth and Yield

The apple trees (cv. Manalagi) involved in the study varied in the stage of development in a range of 9-35 years old (Table 1). The growing stage, however, was mostly around the stage of the highest productivity based on farmers' information. The growth characteristics of apple trees observed in the present study reflect those of semi-dwarf and dwarf type [16]. Variations found in the observed parameters of growth between sites (orchards) were reasonable at the field level as indicated by CV (coefficient of variation). The variations were lower than the variation of growing stage (age), but higher than that of altitude.

In contrast, the fruit yield of apple trees (fruit fresh weight per tree) varied considerably between sites (orchards) as indicated by a CV of 61.9% (Table 2). A high variation was also found in all fruit grades and the fruit size (fruit weight per fruit), while other fruit parameters (fruit diameter, fruit sugar content and fruit firmness) varied only slightly. The fruit weight and diameter observed in the present study were comparable with those of Gala and Daiane apples [4]. Each the observed fruit yield of different tree stages (OYi; *i* = year) was adjusted to the same age (an optimum growing stage). This was approached through a relationship between fruit yield and tree age generated from published data [17]. The relationship could be described by a modified logistic model (Fig. 2a) which was then used to generate an estimated yield

Table 1 The growth description of apple trees cv. Manalagi.

Observation	Min	Max	Mean	sd	CV (%)
Tree age (years)	9	35	19.7	6.7	33.9
Tree height (cm)	240	482	369.8	66.0	17.9
Stem diameter (cm)	8.13	22.2	12.5	3.8	30.9
Canopy height (cm)	129	396	279.9	75.2	26.9
Canopy diameter (cm)	247.5	466	372.2	71.0	19.1
Number of main branches	2	4	3.0	0.5	15.7

Table 2 The productivity and fruit quality of apple trees cv. Manalagi.

Observation	Min	Max	Mean	sd	CV (%)
Fruit yield (kg tree^{-1})	4	110	36.6	22.6	61.9
Fruit quality					
Grade-A (kg tree^{-1})	0	80	8.2	14.2	174.0
Grade-B (kg tree^{-1})	1	35	16.9	9.6	56.8
Grade-C (kg tree^{-1})	2	40	11.5	9.5	82.3
Fruit diameter (cm)	5.2	8.6	6.3	0.7	11.4
Fruit weight (g fruit^{-1})	71.6	330.2	119.0	41.4	34.7
Fruit sugar content (% Brix)	9.5	14.7	10.9	1.0	9.2
Fruit firmness (lbf*)	10.95	25.7	21.0	3.7	17.4

*1 lbf ≡ 4.448222 kg m s^{-2}.

of particular year (EYi). The ratio of the observed and estimated yield of the same year (OYi/EYi) multiplied by a fruit yield of the optimum growing stage would result in an adjusted yield of each orchard of different growing stage (AYj = (OYi/EYi) × 80 kg $tree^{-1}$) with a minimized effect of tree age. However, the adjusted and observed yields were not significantly different based on χ^2 analysis (Fig. 2b).

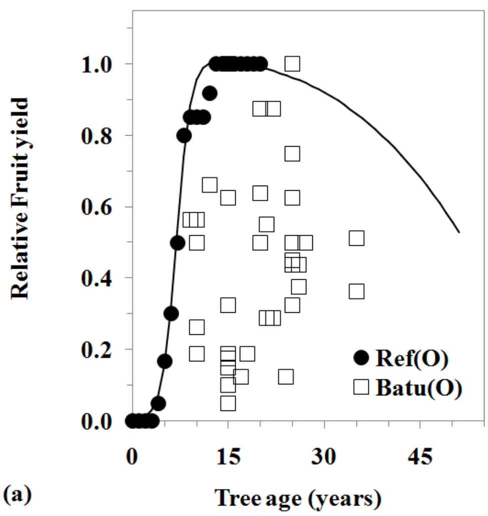
3.2 Altitude and Temperature

The orchards under study were spread out over a landscape of mountainsides varying in altitudes with a range of 861-1,434 m asl.. This brought about a variation in air temperature between orchards as shown by the average of air temperature during the day observed in the field (Fig. 3a). The relationship between the air temperature and the altitude showed a decrease of 0.679 °C in the air temperature with an increase of 100 m in the altitude which is very close to the ELR (environmental lapse rate) value of 0.649 °C 100 m^{-1} [18]. The estimated air temperature at sea surface (the intercept of the relationship) is very close to the actual condition.

The average of air relative humidity (RH) measured during the day tended to increase with an increase in the altitude, but a close relationship between the two variables was not found due to an increase in the variation of RH with an increase in the altitude (Fig. 3b). A strong tendency of RH to decline with an increase in the temperature was found when the data (air temperature and RH) were divided into groups based on temperature classes (Fig. 3c).

3.3 Spatial Productivity Analysis

A close relationship was not found when the fruit yield was plotted as a direct function of the altitude or temperature (Fig. 4). There was, however, a tendency of the fruit yield to increase or decrease with an increase in the altitude or a decrease in the air temperature, respectively. The spatial analysis of GIS PCRaster was then explored to study the effect of air temperature on the fruit yield and quality. This was started with the analysis of variogram that showed a good relationship between semivariance [γ(*h*)] and the distance (*h*) between the orchard sites in the fruit yield and some parameters of the fruit quality (Fig. 5). The variogram models, describing the relationships, were used to generate maps by ordinary kriging with the geostatistical interpolation of the PCRaster (Fig. 6a-g). The map of Grade-A fruits was generated by the



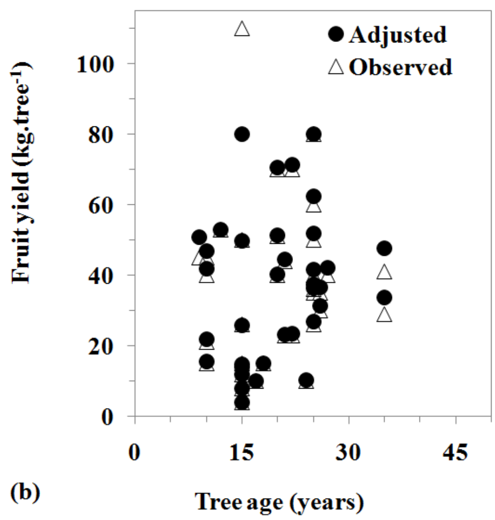


Fig. 2 The relationship between fruit yield and tree age based on data from literature (ref) and data observed in the field (Batu) (a), and for adjusted and actual fruit yield (b). The value of chi-square (χ^2) = 14.45 for the difference between the adjusted and observed fruit yields (*n* = 36). The graph in Fig. (a) was generated by a modified logistic model accommodating aging effect.

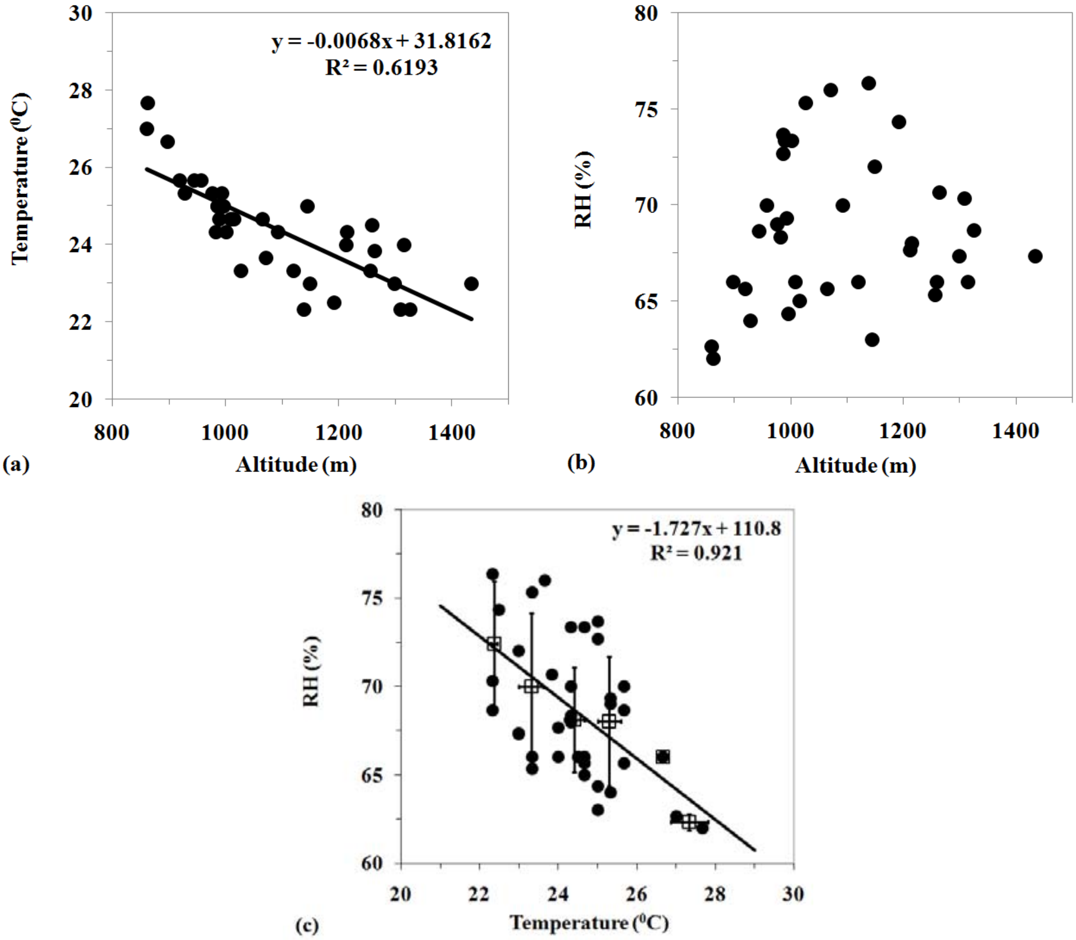


Fig. 3 The temperature (a) and RH (relative humidity) (b) of air during the day as a function of the altitude of the study sites, and the relationship between RH and temperature (c). Each closed symbol represents an average of three measurements (06.00, 12.00 & 18.00), and each open symbol represents an average of grouped data based on temperature classes. The bar (vertical and horizontal) is the standard deviation of the average in each group.

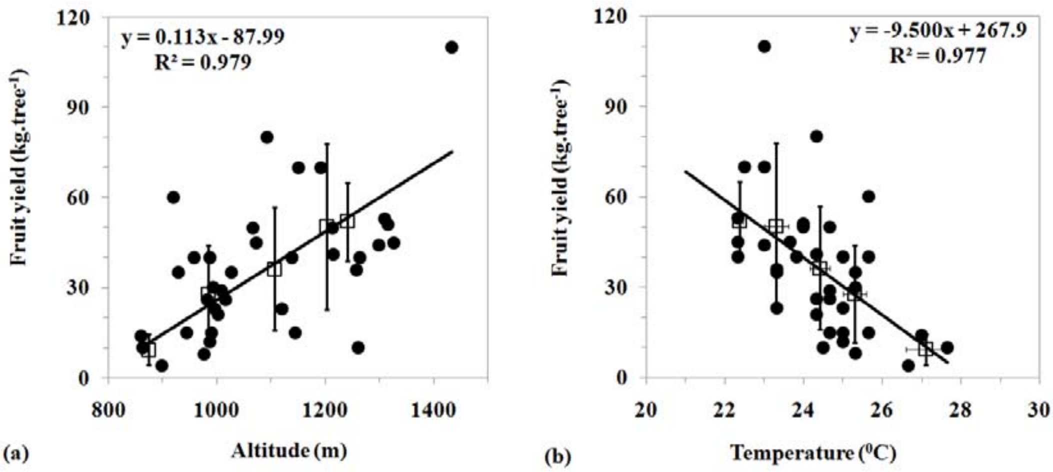


Fig. 4 Fruit yield as a function of altitude (a) and temperature (b). Each closed symbol represents each individual observation, and open symbol represents an average of grouped data based on altitude (a) and temperature (b). Bars are the same as in Fig. 3, and the linear regressions were based on the average values.

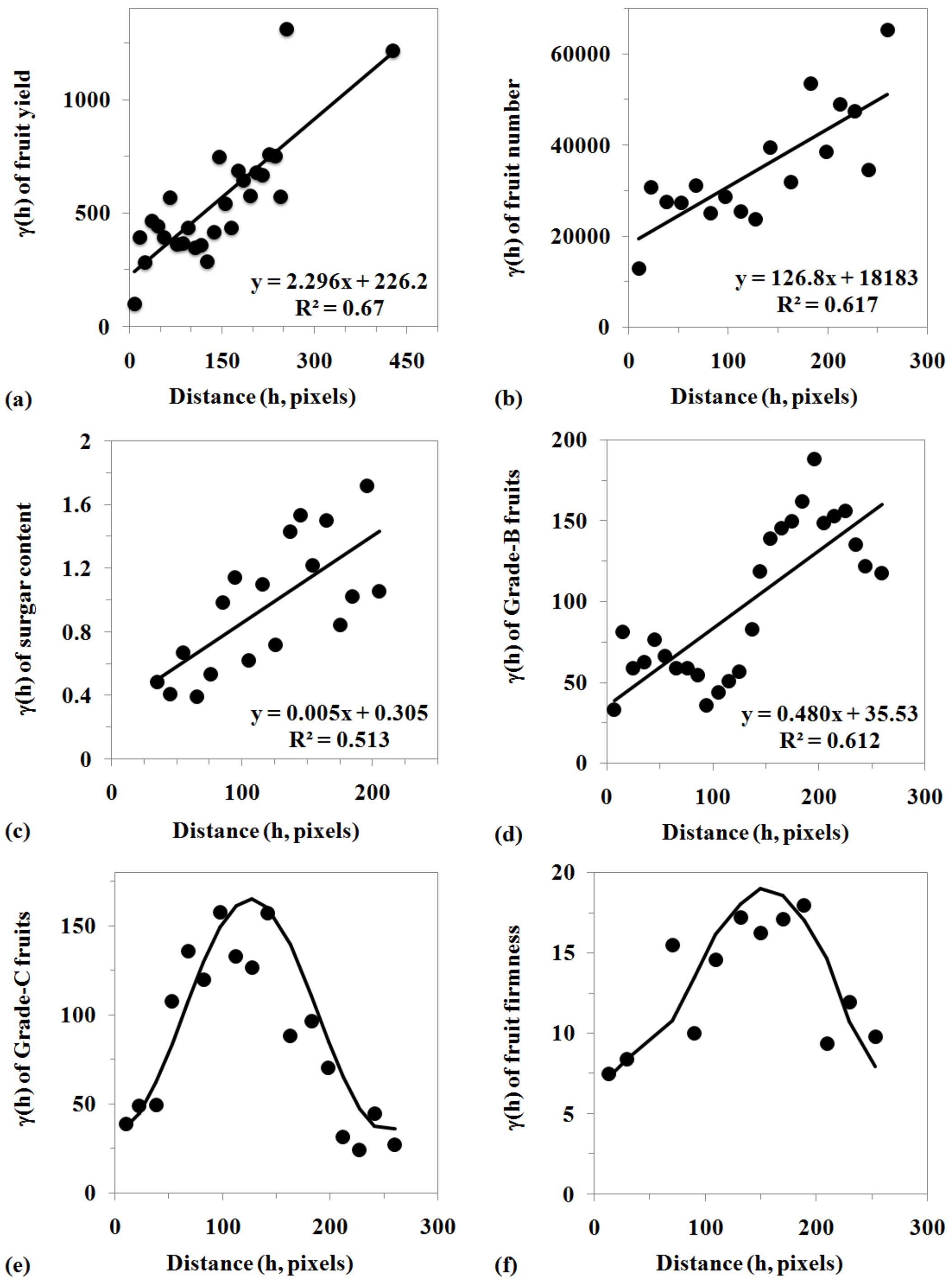


Fig. 5 The semivariance (a) of fruit yield, number, grade (b & c), and firmness as a function of distance (h) between the orchard sites. The graph (d) and (e) were generated with a periodic model.

cartographic modelling of the PCRaster based on the map of fruit yield, Grade-B fruits and Grad-C fruits. The same approach was used also to generate the map of fruit weight (fresh fruit weight/fruit) based on the map of fuit yield and fruit number.

An average of fruit yield or quality from a particular range of altitudes, with the presence of topographic map of the study area (Fig. 6h), could be retrieved from the interpolated maps with the cartographic modelling of the PCRaster. The retrieved

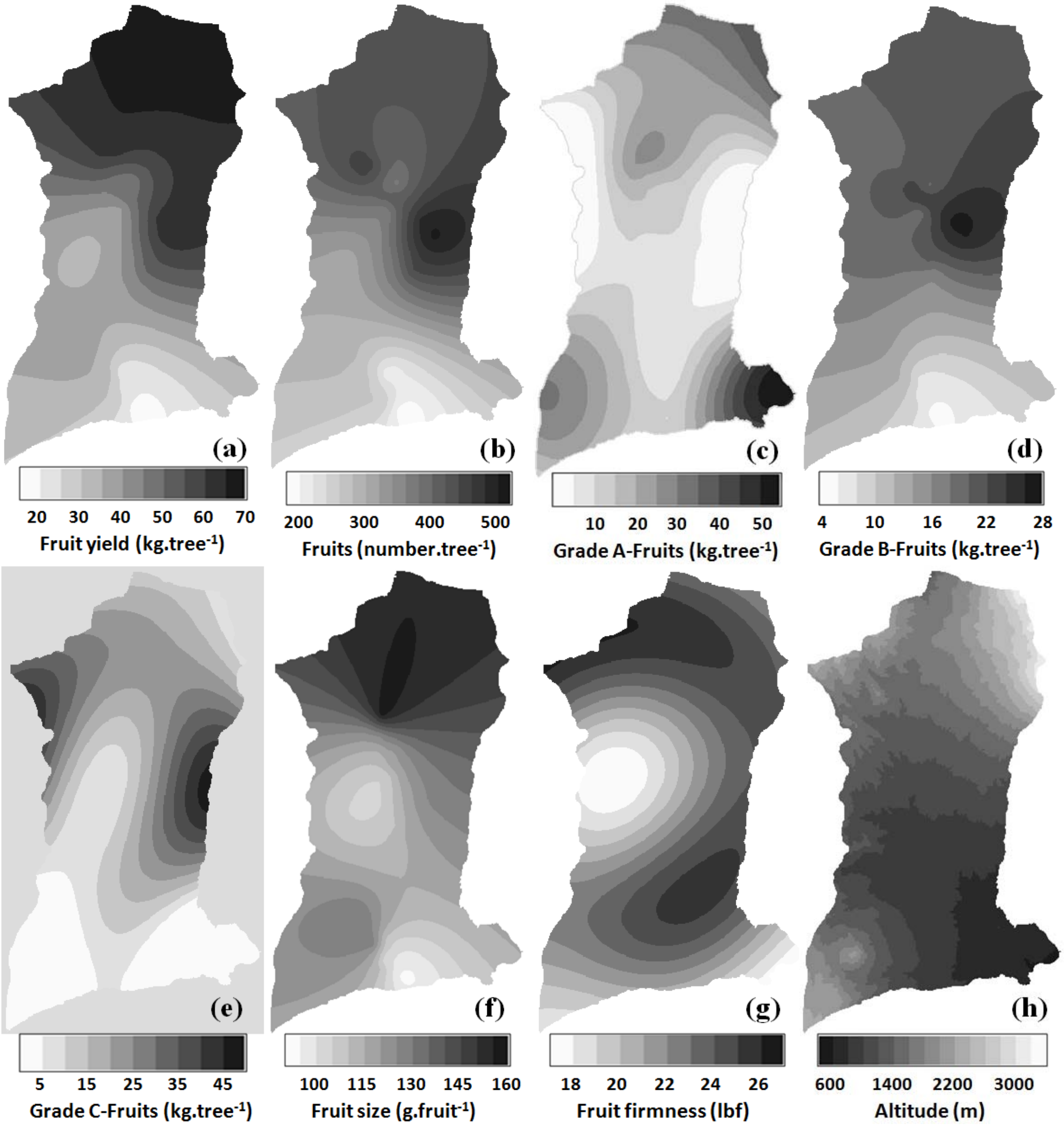


Fig. 6 The interpolated maps with ordinary kriging for the fruit yield, number, Grade (B & C) and quality (weight/fruit and firmness), and the topographic map. The map of Grade-A fruits was calculated from the map of fruit yield and the map of Grade-B & C fruits with the cartographic modeling of the PCRaster.

data were then used to regenerate the relationship between the fruit yield and the air temperature that showed a decrease in the fruit yield with an increase in the air temperature (Fig. 7a). The same approach was used to regenerate the relationship between temperature and the fruit number, the fruit grade or fruit firmness. The number of fruits per tree in relation to temperature showed a trend similar to that of the fruit yield (Fig. 7a). The weight of Grade-A fruits declined sharply with an increase in the air to that at 15 °C. The weight of Grade-B fruits and firmness showed a slight decrease with an increase in the air temperature particularly above 20 °C (Fig. 7b and c). An increase with an increase in temperature to about 200 °C was shown by the weight of Grade-C fruits which declined at higher temperatures (Fig. 7c).

The results of the study showed that a difficulty in the analysis of temperature effect on the productivity of apple trees (Fig. 4), based on the data obtained with a survey, could be alleviated with the application of

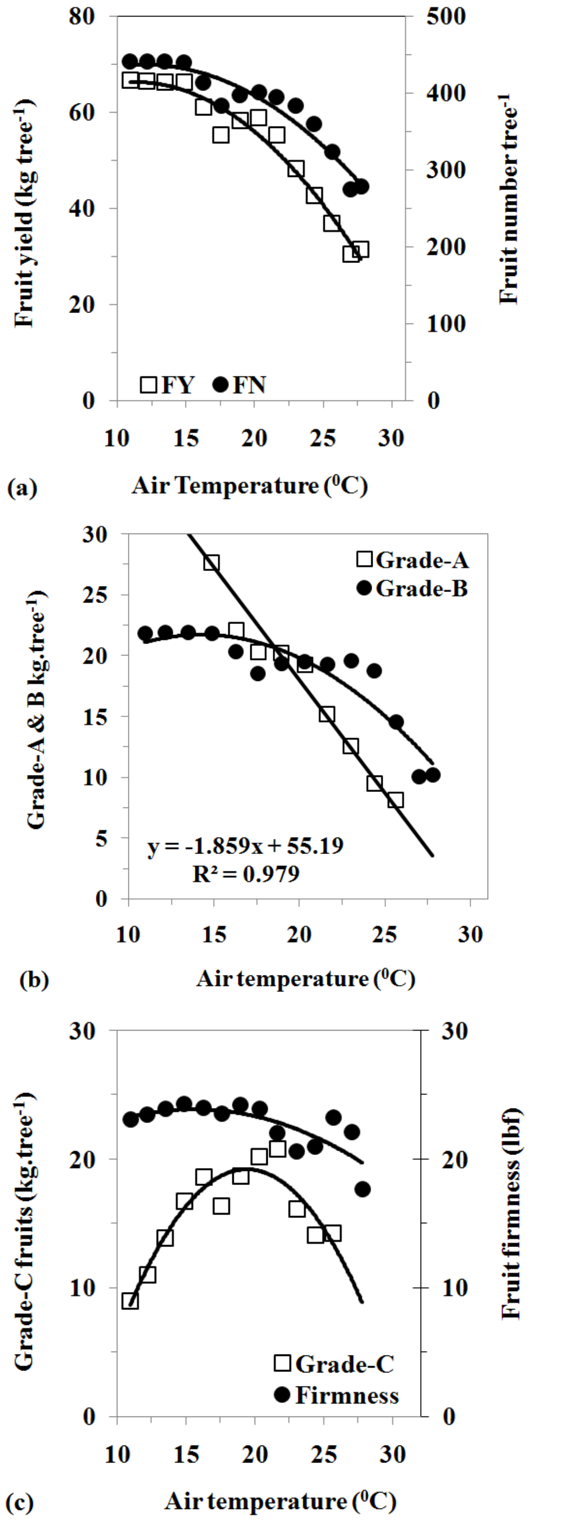


Fig. 7 The effect of air temperature on the fruit yield (FY), number (FN) and quality regenerated from the interpolated maps.

PCRaster as demonstrated in the present study. The analysis focused on the spatial relationship between the fruit yield (fruit fresh weight) and the air temperature was executed mainly with the geostatistical module and cartographic modelling of the PCRaster. It was found that the semivariance of fruit yield was closely related to the distance of orchard sites, and increased linearly with an increase in the distance that suggested a spatial dependence of orchard sites (in term of the fruit yield) on the study area. On the other hand, the altitude in one direction is the most obvious factor spatially dependent on the orchard sites. It is not, however, the altitude responsible for the variation of fruit yield between sites, but the air temperature closely related to the altitude. The distribution map of the fruit yield generated with the geostatistical interpolation (ordinary kriging) was then used to regenerate the average of fruit yield at a particular range of altitude. The same approach was used also for the fruit number, fruit grade (Grade-B and C) and fruit firmness that showed a good relationship between semivariance and distance.

The approach used, that has never been applied so far to study the effect of environmental factors on the productivity of apple trees in the tropics, showed a decrease in the fruit yield with an increase in the air temperature. A decrease with an increase in the air temperature was also showed by the number of fruits, the fruit yield of Grade-A and B and the fruit firmness. The results of the present study are in line with those in Himachal Paradesh (India) that showed an increase in the temperature of apple growing regions, and a decrease in the productivity of apple trees [7]. The increase in temperature (> 1 °C annually) caused chill unit to decline at the altitude < 2,700 m asl., and to increase at ≥ 2,700 m asl., which led to the shift of apple cultivation to higher altitude as observed in region of the present study.

4. Conclusions

The results of spatial analyses showed that the air temperature had a marked effect on the fruit yield that was reduced with an increase in the air temperature.

The number of fruits, the fruit yield of Grade-A and B and the fruit firmness also showed a decrease with an increase in the air temperature. In conclusion, the spatial analysis of the PCRaster was able to demonstrate a close relationship between the productivity (fruit yield and quality) of tropical apple cv. Manalagi and the air temperature (altitude). An increase in temperature particularly above ± 20 °C was followed by a decrease in the fruit yield and quality. It is then very likely that a decrease in the productivity of apple trees in Malang in the last decade is due partly to an increase in the air temperature as a consequence of the global warming and local deforestation.

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References

[1] Arry, The participatory understanding of rural community in the development of revitalization program of apple agribusiness in Batu City, Development Program of Apple Agribusiness, Batu. Local Workshop, Purnama Hotel, Batu 30 Mei, Regional Planning Agency, Government of Batu City, 2006. (in Indonesian)

[2] LERD (Local Economic Resource Development),. Development Program of Apple Agribusiness, Batu. Local Workshop, Purnama Hotel, Batu 30 Mei, Regional Planning Agency, Government of Batu City, 2006. (in Indonesian)

[3] K. Carter, Low-Chill Apples, Cooperative Extension/Botany Plant Sciences Dept. University California Riverside [Online] 2007, http://ucce.ucdavis.edu/files/filelibrary/5764/33384.pdf.

[4] J.L. Petri, F.J. Hawerroth, G.B. Leite, M. Couto, P. Francescatto, Apple phenology in subtropical climate conditions, in: Z. Xiaoyang (Ed.), Phenology and Climate Change 9 (2012) 195-2016.

[5] Anon, Climate Change: Likely Impacts on New Zealand Agriculture, A report prepared for the ministry for the environment as part of the New Zealand Climate Change Programme, The Ministry for the Environment, Wellington, New Zealand, 2001.

[6] F.M. Chmielewski, A. Müller, E. Bruns, Climate changes and trends in phenology of fruit trees and field crops in Germany, 1961-2000, Agricultural and Forest Meteorology 121 (2004) 69-78.

[7] R.S. Rana, R.M. Bhagata, V. Kalia, H. Lal, Impact of Climate Change on Shift of Apple Belt in Himachal Pradesh, ISPRS Archives XXXVIII-8/W3 Workshop Proceedings, Impact of Climate Change on Agriculture, 2009.

[8] D.H. Byrne, T.A. Bacon, Chilling estimation: Its importance and estimation, The Texas Horticulturist 18 (8) (1992) 5-9.

[9] P.C. Andersen, T.E. Crocker, Low Chill Apple Cultivars for North and North Central Florida, HS764, a publication of the Horticultural Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida [Online], 2000, http://dixie.ifas.ufl.edu/pdfs/gardening/apples.pdf.

[10] Anon, A remarkable early-season apple, well-adapted to tropical climates and with a very low chill requirement. Orange Pippin Ltd. [Online], 2011, http://www.orangepippin.com/apples/ dorsett-golden.

[11] D. Karssenberg, P.A. Burrough, R. Sluiter, K. de Jong. The PCRaster software and course materials for teaching numerical modelling in the environmental sciences, Transactions in GIS 5 (2001) 99-110.

[12] D. Karssenberg, K. de Jong, Dynamic environmental modelling in GIS: 1. Modelling in three spatial dimensions, International Journal of Geographical Information Science 19 (2005) 559-579.

[13] C.G. Wesseling, W.P.A. van Deursen, P.A. Burrough, A spatial modelling language that unifies dynamic environmental models and GIS, Third International Conference/Workshop on Integrating GIS and Environmental Modeling, 1996.

[14] P.A. Burrough, D. Karssenberg, W.P.A. van Deursen, Environmental modelling with PCRaster, in: D.J. Maguire, M.F. Goodchild, M. Batty (Eds.), GIS, Spatial Analysis and Modeling: Redlands, California, ESRI, 2005, p. 480.

[15] C. Zllmer, M. Lippe, T.D. Vien, N.V. Dung, T.H. Hilger, G. Cadisch, Development of a Simple PCRaster-Based Model for Rainfall-Runoff Assessment in the Northern Mountainous Region of Vietnam, 2007.

[16] Anon, Understanding Apple Tree Size: Dwarf, Semi-Dwarf and Standard [Online], 2011, http://aces.nmsu.edu/pubs/_h/h-307.pdf.

[17] M.L. Parker, C.R. Unrath, C. Safley, D. Lookwood, High Density Apple Orchard Management, North Carolina Cooperative Extension Service, 1998.

[18] M. Allaby, Dry adiabatic lapse rate, A Dictionary of Ecology, Encyclopedia. com. Apr. 28, 2010, http://www.encyclopedia.com.