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博士学位請求論文

（要約）

Model-aided understanding of farmers and hunter-gatherers in the Neolithic transition in Europe

ヨーロッパにおける新石器時代移行への農耕民族と狩猟・採集民族の現象数理学的考察

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Abstract

Neolithic transition is one of the most significant single developments of human history that consists in a demographic shift from hunter-gatherers to farmers. The Neolithic transition in Europe began the spread of early farming through interactions between farmers and hunter-gatherers about 10,000 years back. Radiocarbon dating was performed by archeologists to gather quantitative data related to the spread of agriculture in Europe. Such an anthropological indication demonstrates that early farming was started to spread over the Europe from a place named Jericho, which was treated as the center of Neolithic transition. It also suggests that early farming advances with almost a constant velocity, which was estimated as 1.0 ± 0.2 km/year. To understand this evidence theoretically, many attempts have been progressed through mathematical modeling. However, most of the existing reaction-diffusion models of Fisher-KPP type are not able to predict the expanding velocity of agriculture in Europe. More precisely, the predicted velocity is faster than the observed one.

We focus on the question: Is there any mechanism for which the expanding velocity of farmers becomes slow down? To answer this question, we claim that "effect of farming technology could be one of the possibilities to make the expanding velocity slow down". For this purpose, we propose a three-component reaction-diffusion system including farming technology effect with two different characteristics of farmers (sedentary and migratory ones) and hunter-gatherers. Chapter 1 of this thesis consists of brief introduction about the Neolithic transition in Europe.

In Chapter 2, we describe the motivation of our research topic. We mention existing modeling approaches on Neolithic transition in Europe and describe that those models seem not to be inadequate to predict the expanding velocity of early farming Europe. The motivation is that to make the expanding velocity of farmers slow down.

In Chapter 3, with this motivation, we propose a three-component reaction-diffusion system (F_1, F_2, H) by introducing two different characters of farmers, sedentary (F_1) and migratory (F_2) ones and hunters (H). We claim a different mechanism from the existing ones that "development of farming technology (γ)" in our system. Ecological evidence of Neolithic transition in Europe indicates that there are two important information: (a) at 10,000 B.C. there were a small population of farmers and rest of the region occupied by hunter-gatherers but however hunters were totally replaced by farmers over time, (b) Neolithic transition advanced in Europe with almost constant velocity.

In Chapter 4, for understanding of the observation, whole hunters' region was replaced by farmers, we focus on the asymptotic behavior of the solutions of our system as an initial-boundary value problem with the homogeneous Neumann boundary conditions and the initial condition is of compact support for F_1 and $F_2 \equiv 0$. Numerical results indicate that whole region of hunter-gatherers completely occupied by farmers after large time and such a behavior of the solution of the system is independent of γ. As for the asymptotic behavior of farmers and hunter-gatherers, our model is satisfied.

In Chapter 5, we focus on the transient behavior of the solutions of the system as an initial-boundary value problem (IBVP). Transient behavior indicates that the occurrence or non-occurrence of traveling wave solutions through exhibiting radial symmetry of expanding pattern. The one-dimensional solution of IBVP with initial function which is of compact support generates traveling wave solution with some velocity which is termed as "spreading velocity" and that velocity becomes slow down, as γ increases. However, the question comes out: How can we characterize the spreading velocity with the traveling wave velocity? Because traveling wave solutions of the system are not unique, since our system is a mono-stable system.

In Chapter 6, we numerically make clear that the relation between spreading velocity and minimal velocity of traveling wave solutions. We apply an approach mentioned by J.A. Sherratt (1998) to our system. This approach is to obtain traveling wave solutions by solving an IBVP. By using his approach, we numerically obtain traveling wave solution with minimal velocity for suitably fast initial decay order. As one of the necessary conditions of the monotone decreasing property of the spreading velocity, we consider the minimal velocities for two limiting systems as $\gamma = 0$ and $\gamma \to \infty$, respectively. This result shows that the minimal velocity when $\gamma = 0$ is faster than the ones when $\gamma \to \infty$.

In Chapter 7, we discuss the question mentioned in Chapter 6. Unfortunately, radial symmetry of expanding pattern breaks down when γ is relatively large, that is, one-dimensional solutions are insufficient to describe expanding velocity. Numerical results also reveal that radial symmetry breaking not only depends on γ but also on the functional form of the conversion rate $P(F;\gamma)$. We also discuss the occurrence of planar instability of traveling wave solutions depending on γ, although the occurrence of planar instability has not yet been shown analytically.

In Chapter 8, We may formally obtain a limiting system by singular limit approach, which surprisingly involves degenerate, nonlinear diffusion. Because of degenerate, nonlinear diffusion, there is not enough regularity in the solutions of limiting system for which usual numerical methods cannot be applied to solve initial-boundary value problem. In this respect, we discuss a strategy to obtain traveling wave solutions by solving an initial-boundary value problem numerically.

In conclusion, the aim this thesis was to predict the expanding velocity of farmers in the Neolithic transition in Europe through a mathematical modeling approach. In order to have better understanding of environmental effect on the expanding velocity, we have proposed a three-component reaction-diffusion system by introducing the effect of farming technology.