This paper quantifies the benefits and limitations of cooperative communications by providing a statistical analysis of the downlink in network multiple-input multiple-output (MIMO) systems. We consider an idealized model where the multiple-antenna base-stations (BSs) are distributed according to a homogeneous Poisson point process and cooperate by forming disjoint clusters. We assume that perfect channel state information is available at the cooperating BSs without any overhead. Multiple single-antenna users are served using zero-forcing beamforming with equal power allocation across the beams. For such a system, we obtain tractable, but accurate, approximations of the signal power and inter-cluster interference power distributions and derive a computationally efficient expression for the achievable per-BS ergodic sum rate using tools from stochastic geometry. This expression allows us to obtain the optimal loading factor, i.e., the ratio between the number of scheduled users and the number of BS antennas, that maximizes the per-BS ergodic sum rate. Further, it allows us to quantify the performance improvement of network MIMO systems as a function of the cooperating cluster size. We show that to perform zero-forcing across the distributed set of BSs within the cluster, the network MIMO system introduces a penalty in received signal power. Along with the inevitable out-of-cluster interference, we show that the per-BS ergodic sum rate of a network MIMO system does not approach that of an isolated cell even at unrealistically large cluster sizes. Nevertheless, network MIMO does provide significant rate improvement as compared to uncoordinated single-cell processing even at relatively modest cluster sizes.